Forest Protection

Books by

Ralph C. Hawley

THE PRACTICE OF SILVICULTURE, fifth edition

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FOREST PROTECTION, second edition

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Preface

The field of forest protection embraces a variety of subjects each of which might be a special study in itself, as for example, forest fires, forest insects, and forest diseases. But all these diverse subjects are related and have a common meeting ground, where the forester is concerned, in their injurious influence upon the forest. Protection of the forest from its numerous enemies is essential for success in the management of forest lands. The student of forestry can best gain and appreciate this viewpoint by considering forest protection in its entirety in relation to the forest.

In a properly balanced undergraduate forestry course, time adequate to develop specialists such as forest entomologists, forest pathologists, or forest fire experts cannot be afforded. What can be done is to equip the student with a well-rounded knowledge of the whole problem of forest protection in its relation to the growing of forests. The book has been written with this purpose in mind.

The book is not intended to be an engineering or administrative manual for any of the phases of forest protection. Valuable as these manuals undoubtedly are for the practicing forester, they are not particularly suited for student instruction in schools giving a full course in forestry. The principles which underlie protection, rather than detailed instructions for carrying on specific types of work, constitute the material that should be covered in a course in forest protection.

Technical names of the tree species mentioned in the text have been listed in the Appendix. *Sudworth's Check List*, with changes as approved by the U. S. Forest Service Tree Name Committee in January 1940, has been followed with respect to all native species.

Technical names of fungi and insects mentioned in the text are also given in the Appendix.

R. C. Hawley
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CHAPTER 1

General Considerations

THE PLACE OF FOREST PROTECTION

Forest protection is that part of silviculture which deals with the protection of the forest against various injurious agencies. It is an essential part of silviculture and must be given a place in any thorough covering of the subject. Forest protection, however, may be studied separately from the other parts of silviculture. When this is done, the fact that forest protection is an important part of silviculture should never be forgotten. The object of a general course in forest protection is to acquaint the forester with all branches of the field and to ground him thoroughly in the interrelations between forest protection and the other parts of silviculture as well as forest management.

The injurious agencies are so numerous and many of them are so destructive that the production of profitable tree crops is impossible unless adequate protection is afforded. This situation is analogous to that existing in all other branches of plant crop production. Protection is fundamental for growing either agricultural or forest crops.

Appreciation of this fact with all that it implies is always slow to develop in regions where forestry is in the initial stages. With the passing of the virgin forest, which was produced without conscious effort, the growing of tree crops starts. As these new crops are established, cared for, and observed, it dawns on the practitioner that his most important and difficult problem concerns protection from various enemies—many of which threaten complete ruin to the crop. Each locality has problems of protection peculiar to itself, but the same broad types of enemies occur throughout the world. In America four great types of injurious agencies assume paramount importance, namely, fire, insects, fungi, and domestic grazing animals.

Until recent years, protection in America centered around the protection of old growth timber or preservation of values already existing in the virgin forest. Now forest protection in this country has entered the stage in which emphasis is placed upon the protection afforded the growing crop. It is difficult for us, because experience is lacking, to understand how important a part forest management and the practice of silviculture itself may play in controlling or at least tempering injurious influences and in minimizing the damage which they cause. The least expensive yet most effective forest protection can be secured only through sound methods of management and of silviculture applied on a forest property over a long period of time.

The problem should not be viewed simply as a question of organizing on the spur of the moment to meet each injury as it occurs. That is a hand-to-mouth procedure useful temporarily in times of emergency, but not the sort of policy which should be accepted as satisfactory in a planned system of forest management. Instead, all potential sources of damage should, if possible, be recognized and evaluated before the emergency arises. Under this principle the management of the property is so conducted that losses from injurious agencies, when they become threatening, are held to the minimum damage. Often the activity of one injurious agency leads directly to the development of some other source of injury. The forester must know the original source and be able to plan his protection to avoid or minimize the danger from that source.

Injurious agencies may be made potentially more dangerous or, on the contrary, damage from them may be minimized as a result of silvicultural operations in the managed forest.

Injuries to the forest ordinarily can be held to relatively small proportions where silviculture is applied intensively. For example, a good transportation system with numerous wood roads, which enables frequent return to all parts of the forest, makes it possible to salvage injured material and, hence, to hold damage to a minimum. Furthermore, where management is intensive, the forest ordinarily is staffed by a good class of employees, adequate in number to provide frequent and close observations leading to discovery of sources of injury in the early stages of their attack.

In contrast to the favorable protective influence which the managed forest may exert, it may also increase the likelihood of injury. The managed forest usually contains fewer species (often only one species) than the virgin forest. This scarcity of species changes the long-established composition of the natural forest and thereby modifies biological

relationships. In the long run an increased amount of injury may result.

The probability of such changes is particularly true in the first stages of forestry through which the United States is now passing. The economic necessity for heavy cuttings in some places and the predominance of inferior species in others, coupled with the gregarious habits of many American tree species, has already led to the establishment of numerous pure evenaged stands of large size. There may be nothing unsound in this situation. In fact, the original or climax forest may be pure, as is the case with ponderosa pine. Pure stands oftentimes are just what the forester wants, and under correct management they may be as productive in volume as, and more productive in financial return than, those of mixed composition. The investigations of Burger (1928) * in Switzerland indicate that pure and mixed stands have approximately the same volume increment. However, he prefers mixed stands for their more effective soil protection, greater ease of regeneration, and greater safety from damage. Champion (1933), who attempted to find specific instances in Europe of losses directly attributable to the pure composition of the stand, reports negative results from his search.

Whether pure or mixed crops are more productive is beside the point as far as protection is concerned. The controlling factor should be safety from injurious agencies. It is true that large evenaged pure stands are concentrated risks in that an enemy gaining a foothold and finding suitable conditions for development may cause heavy losses. Safety is frequently secured by scattering risks. This idea applied to forest crop production suggests the advisability of employing one or more of the following steps: (1) mixing several species in each stand, (2) growing timber in unevenaged stands or restricting the size of an evenaged stand to a relatively small area that is adjoined by stands of other ages, (3) where pure stands are grown, having the individual stands of small size.

However, the higher financial returns likely to be secured from pure than from mixed stands, and the greater simplicity in management of the former, will lead to the maintenance of many pure forests which, if made of the right species in small stands and skillfully managed, should be successfully grown. To be safer than pure stands mixed stands must contain some injury-resistant species as well as the nonresistant. The possibility exists that these resistant species may turn out to be less resistant than when first considered. They may likewise be so much less productive than the nonresistant species as to offset greater damage

* References cited will be found at the end of each chapter.

to the latter. The forester must attempt to weigh properly all these factors in planning his forest.

An unevenaged stand in which all ages from the seedling to the mature tree were intermingled undoubtedly would be the safest age form. The difficulties of obtaining and maintaining this type of age arrangement are so great that it will rarely be developed. Adequate irregularity will be secured if evenaged groups of different ages are interspersed. Under favorable conditions, small evenaged stands of several acres each adjoined by stands of other ages will be safe.

Experience with this system in Germany is instructive. In that country widespread use of the clearcutting method with artificial reproduction, *the use of species not suited to the site,* is now recognized as the primary source of far-reaching and extensive injuries to the forest. This illustrates the fact that adequate forest protection during the life spans of the present and the succeeding forest crops often hinges upon details of forest management and silviculture, which at first thought might not seem important to forest protection. To sum up, it may be that it is more dangerous to grow a forest under intensive management than to let it develop unhampered. But it should be borne in mind that the unmanaged or uninhibited forest which in some quarters is regarded as "safe" from injurious agencies actually is simply the composite vegetation which the injurious agencies on that location have not destroyed. Such a forest, while perhaps absolving the forester of all responsibility for results, does not measure up to modern standards in productivity.

Essentially the same idea is brought out by Weir (1936, p. 3), who points out that, as man enlarged his power over nature by, for example, the art of cultivating the ground and domesticating animals, he assured himself a less precarious and more abundant existence. This applies in forest crop production as well as in agriculture.

Wagner (1930, p. 331) recognizes that it may be more dangerous to manage a forest intensively than to let nature determine the composition. He indicates that forest management must continually progress toward more intensive application and must not return to the old "safe" unevenaged mixed forest.

CLASSIFICATION OF INJURIOUS AGENCIES

In the classification of agencies injurious to the forest considerable choice of arrangement is available. The arrangement given in this

book is believed to be the most logical. The subject is divided into six general classes of injurious agencies listed as follows:

1. Forest fires.
2. Plants, including fungi, mistletoes, and forest weeds.
3. Insects.
4. Domestic animals.
5. Wildlife (animals other than insects and domestic species).
6. Atmospheric agencies. Under this heading are included injuries from heat, frost, drought, water (including injury from floods, erosion caused by water, landslides, snow, ice, hail, and avalanches), air movements (including the effects of drifting sand and erosion caused by wind), lightning, poisonous gases, and smoke.

In the minds of most men managing American forest properties, fire has held first place among destructive agencies against which the forest must be protected. This viewpoint has resulted in directing protection efforts principally against fire, often with scanty attention paid to protection against other types of enemies. Centering of interest on fire has been a natural and logical development, since fire threatens immediate and total destruction of the forest (often within a few hours), consumes neighboring buildings, and may destroy human life. As an essential for growing forest crops, the danger of destruction by fire must be reduced. However, the urgent necessity for accomplishing this should not cause neglect of the other branches of protection.

In a given region, either insects or injurious plants may, and often do, cause more loss in a year than fires do. Their work of destruction is generally slower, less spectacular, and not so readily susceptible of quick control as fire. However, they are at work at all times, and no forest area is free of them. Injuries inflicted by grazing animals are frequent and widespread. It is probable that in some parts of America losses from grazing injury exceed those from any other source. Over restricted areas, damage from wildlife may prove the most important source of loss.

The extent of forest damage caused by atmospheric agencies, although continually in evidence, is even more difficult to estimate than that caused by other agencies. The effects of heat, cold, drought, water, and other atmospheric agencies are so universal and yet so intangible of appraisal that comprehensive estimate of the injury is impracticable. Without doubt the sum total of such injuries may exceed in some years those caused by other enemies. Certain it is that abnormal weather is at the root of many of the sources of injury not classed as atmos-

pheric, such as attacks of many insects and fungi. Though often overlooked, weather is the underlying cause of the injury inflicted on the forest by fires. Without favorable weather, fires cannot burn.

The significant point to remember when comparing damages from different sources is that any one of these injurious agencies may be of critical importance locally and powerful enough to destroy the forest. If this fact is kept prominently in mind the proper attitude toward forest protection follows naturally and leads the forester to appreciate the necessity for a well-balanced outlook on the protection problem.

Forest protection in its application to controlling injurious agencies includes a highly specialized group of subjects. The classification and description of injurious agencies, the scientific facts which must be known in order to have a sound basis for determining control methods, and the administrative problems connected with control and prevention of losses call for the development of specialists in several of the more important branches of forest protection. No one forester is likely to be an expert in all phases of protection, and it is unnecessary that he be a specialist in even one branch.

Every forester, although not a protection specialist, must grasp the importance of the protection problem, must possess the ability to discover the injurious agencies, must understand the principles governing control of the enemies which he finds in his forest, and, finally, must be able to organize and apply the necessary control measures. For help as regards technical details concerning any injurious agency he should call upon the specialist in this field. In the long run the forester in charge of a forest will control and carry out the necessary protective measures, fitting this work in with his other activities. The protection specialist in whatever field he may be working should recognize that his job is to cooperate and assist in the forest management of the area and that his line of protection is not an end in itself but important simply as an aid to better forest management.

PREVENTION—ITS IMPORTANCE

The most important principle in forest protection for all types of injurious agencies is that prevention of the start or development of an injurious agency is far more effective than attacking after the damage is under way.

Within recent years recognition of prevention as the most important principle in forest protection has come to be universal. However, it is doubtful whether the extension of this idea throughout all silvicultural

and forest management operations for the long-period viewpoint has yet gained adequate application. Results in preventing damage to the forest secured by wise application of management and silviculture are a long time in coming, *but ultimately the results so secured are more enduring and less expensive than more direct methods of protection.*

A thorough appreciation of forest protection is fundamental for intelligent management of a forest property. The protection goal is the safeguarding of the continuous productivity of the property. This can be accomplished most effectively by growing a forest of such character that injury of an extensive and serious nature is prevented. Wagner (1930) has stressed this idea, which he considers of primary importance if the new and increased possibilities of injury, introduced by forest management, are to be overcome.

Evidently the word "prevention" should be used with a broader meaning than ordinarily is given to it in forest protection. Admittedly the fact has been stressed that prevention is of primary importance in securing cheap and effective protection. This, however, has usually been interpreted as meaning the taking of certain definite steps toward hindering one of the many injurious agencies from developing to a point where it could cause serious damage.

In addition, prevention should be interpreted as implying the development, through long-continued and careful management, of a forest that inherently will be safeguarded against the total of injurious agencies which might cause serious destruction. Ultimately the forester himself, through his understanding of this important principle and through this long-continued and skillful molding of the forest into the character desired, will be more powerful in preventing and controlling the work of injurious agencies than the numerous protection specialists.

WHAT THE BOOK INCLUDES

Substantial advances in developing methods of controlling the various enemies of forest crops have been made to fit the wide range of forest and economic conditions in America. However, these methods of control are even yet largely undeveloped, except protection against fires, in which, because of the necessity for immediate action and because of the practicability of direct control, much greater progress has been made than in other lines. This is one reason why fire is treated more fully in the text than are the other injurious agencies.

Within the limits of a single volume forest protection cannot be

covered in full detail. All that will be attempted here is to select the more destructive injurious agencies and to present (in the succeeding chapters) for each the following information:

1. Description of the damage caused.
2. Character of the injurious agency.
3. Discussion concerning the methods of control.

Particular attention will be given as to how and to what extent methods of silviculture and forest management can be utilized to assist control.

In studying forest protection it will be found that frequently the details of control suggested for specific enemies of the forest conflict with the treatment recommended for control of other enemies. Quite evidently some compromise must be made. This is often accomplished involuntarily, since not all enemies of the forest are threatening simultaneously on a given forest area. Furthermore, methods of control must be influenced by the economic situation, which may sometimes prevent putting into practice the theoretically best steps for immediate protection. The forester must not expect that completely efficient protection can be secured all at once. Oftentimes the condition of his forest requires certain types of cuttings which he knows are not the best in the long run but are necessary to meet the exigencies of a given situation.

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CHAPTER 2

Man as a Source of Injury to the Forest

Before considering in detail each of the six major classes of injurious agencies, the part which man plays as regards injury to the forest should be emphasized.

Man himself is a primary source of injury to the forest. Part of this injury is directly caused by him and part follows indirectly as a consequence of his activities. He contributes to so much of the damage caused in the forest that his influence is felt either directly or indirectly under each of the six major classes of injurious agencies.

A large share of the damage resulting from forest fires is chargeable to man since the major proportion of all the forest fires in America are caused by his carelessness. In the period 1942–1946 at least 85 per cent of all the forest fires in the United States were man-caused fires. Most of the fires started by man originated through carelessness although a significant part of the man-caused fires were started intentionally. The education of man for the purpose not only of correcting his carelessness and preventing his intentional setting of fires but also to give him the right viewpoint on forest protection is the most important and effectual line of protection activity which can be undertaken.

Man has been directly responsible for establishing dangerous plant pests in this country through the introduction of harmful insects and fungi from foreign countries, usually on importations of plant materials. The gypsy moth * and the chestnut blight are two well-known examples of imported pests. The extermination of the chestnut throughout its range by the chestnut blight ranks as a major forest

* Technical names of insects, fungi, and trees referred to in the text will be found in the Appendix.

catastrophe. Only increasing vigilance in the enforcement of laws forbidding or strictly regulating importation of material potentially capable of harboring plant pests will prevent similar disasters.

Domestic animals are often placed by man in the forest and allowed to graze there. The injury caused by these animals, which at the worst may amount to destruction of the forest, can thus be attributed indirectly to him. It is within man's power to withdraw the animals or to regulate their grazing use of the forest.

Most, and possibly all, severe cases of injury to the forest by wildlife are caused by man as a result of his protection of wildlife or by other types of his interference with its environment. Such action usually results in an abnormal increase in numbers of certain forms of wildlife without corresponding increases in available food. The forest suffers accordingly.

One thing which man cannot be blamed for is the climate. The atmospheric agencies injuring the forest are beyond man's control. Nevertheless the effects which many atmospheric agencies have on the forest can be intensified or minimized depending upon the treatment which the forest receives throughout its life.

Man is responsible for injuries caused to the forest by poisonous fumes from smokestacks and manufacturing plants. Fortunately the emission of smoke and poisonous fumes from industrial plants can readily be prevented, and, if not voluntarily abated such nuisances should be restrained by legislation.

The forest often is injured by the human trespasser who steals forest products or commits acts of vandalism. Sometimes the trespassing is involuntary, the result of the lack of easily found boundary marks. For protection against this class of injury, good surveys and the clear marking of boundary lines in the forest are essential. An alert forest personnel, by promptly finding evidences of human trespass, will help in minimizing damage of this type. As a last resort against the trespasser the police function of the government can be utilized.

The forest can also be injured by the removal of its litter annually or periodically for mulching and fertilizing agricultural crops, for bedding domestic stock, and for other purposes. Long-continuing removal of forest litter for such uses is a common practice in European forests and results in a lessening of the growth per acre, sometimes amounting to a reduction of more than 30 per cent (Wiedemann 1935). The results of an investigation by Jemison (1943) of the effect of litter removal on diameter growth of shortleaf pine have verified European experience. However, since in this country the forests treated in this

way are limited in number, removal of litter remains a minor source of injury in America.

Other minor injuries caused by man are the compacting of the soil, destruction of forest litter, and reduction in forest density which are inevitable where large numbers of people use the forest at frequent intervals. Most of such forms of injury occur in the neighborhood of camp grounds and in forest areas which have been set aside as parks. Where the most profitable use of the area is for recreational purposes the compacting of the soil, together with injury to tree roots and mechanical injuries to the tree trunks, must be expected as normal. The damage to forest areas so treated for decades is considerable. Lutz (1945) investigated conditions in Connecticut State Parks on picnic grounds and on unused forest areas and found significant changes for the worse in the physical characteristics of the soil on the picnic areas. As a consequence, cultivation of the surface soil and probably the application of fertilizers will eventually be needed.

Under certain circumstances destructive logging, as its name implies, may ruin the forest. The harvesting of mature timber does not in itself constitute destructive logging. Rather it is other details characterizing the operation which result in destroying the forest. Chief among these is failure to provide for the establishment of another crop of good trees after the mature timber is cut. Destructive logging assumes also that young and middle-aged timber is destroyed or cut too soon and that cuttings injurious to the soil are made. The net result is that the future production of forest crops on the area is greatly reduced or entirely stopped. Man has carried out destructive logging on millions of acres of forest land in America, and in some parts of the country is still continuing the procedure. The remedy lies in educating the property owners to the fact that less destructive methods, which are practicable, can be employed. Another alternative is to enact the necessary legislation which will stop destructive logging.

A major source of injury caused by man is that for which the owner and the forestry staff are responsible through poor management of the forest resource in one or more ways. Frequently the man at the head lacks knowledge of the interrelations between the various injurious agencies threatening the forest, the management policy, and its application in the woods. Lucky indeed is the forest manager who sooner or later does not suffer a catastrophe in his forest which sound planning might have avoided. Few if any businesses need more careful planning ahead for long periods than the growing of forest crops.

Over the lifetime of a forest crop atmospheric factors are of primary

importance not only in determining the growth of the crop and in the direct injury caused the forest but also in the effect which they have in making the forest more susceptible to the attacks of insects, fungi, and fire. In growing forest crops man too often has failed to develop and maintain a forest which would be more resistant to injury by atmospheric factors and other agencies. Frequently his work has tended to increase the possibilities of injury.

Potential resistance of a forest crop throughout its life to damaging agencies depends first upon the form of the stand. Irregularity or lack of uniformity is a safeguard against extensive damage.

Already on page 3 attention has been called to the dangers which come from managing the forest in large stands of a single species. Man is responsible for the development of some of these big pure evenaged stands. He should strive to keep the forest either in unevenaged form or in small evenaged units and in some cases to develop mixed stands. Often the economic advantages of pure stands are great enough to justify their maintenance, particularly where they occur in virgin forest form.

Another mistake which may be made is using a reproduction method in an unsuitable situation. The commonest case would be in employing the clearcutting method with artificial reproduction on an extremely exposed site. However, from the protection standpoint practically any reproduction method may be safely used provided the proper precautions as to form of the stand are observed.

Failure to make thinnings or other types of cuttings at frequent enough intervals to keep the trees in vigorous condition with adequate room for each individual often results in heavy losses from drought.

Careless selection of seed and plant material for use in artificial regeneration may result in serious injury to the productiveness of the forest. One of the best illustrations of this may be seen in the Scotch pine plantations which have been made frequently in the northern and eastern states since the start of this century. Most of these plantations have proved to be of inferior races of this pine and therefore will never produce Scotch pine timber of the quality grown particularly in northern Europe.

Possibly the planting of this exotic species was a mistake in the first place, although there is evidence to indicate that the best races of Scotch pine can thrive in parts of this country.

Incompetent personnel in any grades of the organization may result in damage to the forest. Intensive application of silviculture is impossible without a trained staff. Otherwise the technical operations,

such as timber marking, will be poorly applied, and the actual work in the woods may be wasteful.

There is abundant opportunity for damage to the forest in the process of cutting and removing wood products from the forest. The fellers may, if careless, seriously injure standing timber and reproduction. Control here must be through the employment of good workmen or in adequately training those already on the property. Control of the direction in which each tree may be felled is often practicable and may greatly lessen damage due to felling. It is often necessary to train the workmen before unnecessary waste can be eliminated. Losses from felling operations can be prevented most effectively through the concentration of cuttings on areas upon which there is no reproduction (unless it be small seedlings) and upon which all other trees will be cut. This does not imply that clearcutting must be used, but it does indicate a systematic harvesting of the forest in pieces large enough so that the trees removed can be felled upon the cutting areas rather than into adjoining masses of reproduction or young timber.

Other serious injuries are caused during the removal of the forest products from the area after cutting. In the work of transporting forest products, standing trees may be barked and thereby exposed to subsequent attack by fungi and insects. Serious loss may therefore take place before the injured trees are harvested. This is of importance when the barking occurs on young timber, which must remain many years before becoming merchantable, as contrasted to older timber which will be cut within a relatively few years.

Heavy logging equipment such as tractors may compact the soil and appreciably decrease the rate of water infiltration in heavy soil types (Munns 1947).

Damage due to removal of timber, especially damage to roots near the surface, can be eliminated or lessened if logging is done on the snow. Unfortunately in many parts of the country deep snows cannot be depended upon and logging must be done when the ground is bare. Less injury is done if the transportation takes place in the dormant season. Separation of age classes so that each grows upon a separate area, and arrangement of the areas for cutting so that there is no extraction of timber through the younger age classes, are in the long run the best methods of avoiding injury from transport of forest products.

If timber is sold on the stump and the purchaser does the logging, the methods of logging which may be used should be specified. Methods of logging vary in their destructiveness to reproduction and young

growth; those involving hauling the logs by steel cables operated at high speed by donkey engines tend to be the most destructive.

The purpose of this chapter will have been accomplished if the reader at this point recognizes the important influence which man should exert in the protection of the forest. He is directly or indirectly responsible for a large share of the injury suffered.

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CHAPTER 3

Forest Fires: Their Effects

Forest fires are in the main injurious to forest production. In certain instances, beneficial results may accrue. There exists such a wide disparity between the relative importance of the injurious and beneficial influences that the beneficial ones are often overlooked. In this chapter the effects of fires are assumed to be injurious unless otherwise specifically stated. The beneficial effects are considered in a special section, pages 28 to 32.

ANNUAL FIRE LOSS

A study of the statistics compiled and published each year by the Division of Cooperative Forest Protection, U. S. Forest Service, shows that during the last 5-year period (1942–1946) the average number of forest fires per year was 169,355 in the whole United States (exclusive of Alaska). Of these fires 74,423 burned on protected lands, namely lands that are under an organized system of fire protection. The rest of the fires, nearly 95,000 each year, occurred on unprotected lands. At first sight it would appear that fire control in this country is not very effective since on the average only less than 25 per cent fewer fires occurred annually on protected lands than on those unprotected from fire. These figures become significant only when it is realized that the protected area during the 5-year period averaged nearly 498,000,000 acres while the unprotected area was about 129,000,000 acres. Consequently 56 per cent of the total number of fires (those which burned on unprotected areas) occurred on only 20 per cent of the total forest area.

An annual average of nearly 24,000,000 acres was burned over by all reported fires. However, only about 14 per cent of this burned-over

area was on protected lands; 86 per cent occurred on unprotected lands. Expressed in another way, only an average of 0.7 per cent of the protected area burned over annually while more than 15 per cent of the unprotected area burned over each year. Surely this indicates that forest fire protection can be effective.

Noteworthy advances toward controlling forest fires and reducing the loss from this cause have been made in the last 35 years, or since the start of organized forest fire control after 1910.

The estimates of damage recorded in the U. S. Forest Service statistics indicate annual damages of approximately $35,000,000, of which over $9,000,000 is assigned to the protected lands and the balance to unprotected areas. This estimate presumably includes all tangible damage to timber, reproduction, forage, and improvements. It amounts to less than $3 per acre of the protected area burned over. On unprotected areas the damage is estimated at about $1.30 per acre burned over. This difference is attributed to the much greater value of the forest crops on protected lands. These figures may be taken as conservative. No allowance is made here for many other losses intangible and indirect but exceedingly serious, such as deterioration of the site and effect on runoff of water and on stream flow. The intangible or indirect losses resulting from forest fires are difficult to appraise but in the long run may exceed those of a more direct and easily ascertainable character.

About 75 per cent of the acreage of unprotected forest lands in the United States are in the southern states. Furthermore they have even a larger share of the burned-over acreage and appraised damage assigned to all unprotected lands. The opportunities and need for improvement in organized forest fire protection may be said to be greater in this region than elsewhere in the United States.

The general trend today in the United States is toward lower forest fire losses as a result of the constant strengthening of forest fire protection, operating both to bring each year more previously unprotected lands under protection and also to improve the methods of control on lands already under protection.

For example, comparing the period 1932–1936 with the years 1942–1946, we find that there is a large decrease both in total area burned over and in damage as indicated in the table. The reductions have come principally on the unprotected lands as a result of bringing more of such areas under protection. The relatively smaller improvement on protected lands represents actually more progress than the figures

indicate since the 1932–1936 figures apply to a protected area of about 454,000,000 acres while the 1942–1946 data apply to approximately 498,000,000 acres. There has been no significant change in total number of fires, although the number on unprotected areas has dropped while those on protected areas have risen. The reason for the rise in number of fires on protected lands may be the increase in the acreage protected, combined with improvement in the gathering of fire statistics.

	Annual Average During Period			
	1932–1936		1942–1946	
		Per Cent		*Per Cent*
Total forest area in acres:				
Protected areas	454,000,000	68.4	498,000,000	79.4
Unprotected areas	210,000,000	31.6	129,000,000	20.6
Total areas	664,000,000	100.0	627,000,000	100.0
Area burned over in acres:				
Protected areas	3,660,842	9.2	3,430,364	14.3
Unprotected areas	36,698,730	90.8	20,391,422	85.7
Total areas	40,359,572	100.0	23,821,786	100.0
Damage:				
Protected areas	$10,323,194	20.9	$ 9,245,998	26.1
Unprotected areas	39,029,846	79.1	26,061,832	73.9
Total areas	49,353,040	100.0	35,307,830	100.0
Number of fires:				
Protected areas	66,101	39.4	74,423	44.1
Unprotected areas	101,811	60.6	94,932	55.9
Total areas	167,912	100.0	169,355	100.0

In the long run, forest fire losses (provided the efficiency of prevention and control is held constant and given the same accuracy of statistical report) may show a tendency to increase because of the increasing total value of forest property and the increasing use of the forests. On the other hand, improved fire prevention and control will work in the opposite direction not only to reduce the total amount of the loss but also to decrease even more strikingly the loss expressed as a percentage of the total forest values. The net result should be a gradual reduction in the average annual fire loss.

As compared with the estimates of damage caused by insects, the average annual fire losses appear to be smaller. Study of the situation over the country as a whole tends to confirm this impression. Estimates of the annual loss from plant diseases are so difficult to make that a definite comparison between fire and plant diseases is practically impossible. It is estimated for the decade 1934–1943 that, together

with insects, diseases were responsible for an average annual drain on the forests of this country of 622,000,000 cubic feet compared to an average annual drain of 460,000,000 cubic feet from fire during the same period (Anonymous 1947). It is believed that insects should be ranked first, on the basis of present damage, and fire second, with plant diseases third—with the reservation that where an epidemic plant disease like the chestnut blight becomes serious the loss will exceed that caused by either fire or insects.

However, it must be remembered that indirectly fires are a contributing cause in much of the damage charged against insects and fungi. The wounds and weakened condition of trees resulting from fires frequently enable plant and insect pests to gain foothold and increase the injuries started by fire. Furthermore, the reason why fire today appears as secondary to insects in causing damage is that already substantial progress has been made in preventing the start of forest fires and in controlling those that do start. If no more organized effort was spent on the prevention and control of forest fires than is directed today to fighting forest insects and fungi, the damage from fires would be stupendous and would exceed that from any other source. Fire is a sudden and spectacular destroyer on a vast scale, but it admits of more effective control than some other enemies of the forest.

CLASSIFICATION OF THE INJURIES CAUSED BY FOREST FIRES

The injuries caused by forest fires may be classified under the following heads, of which the first four have a direct relation to the results of applied silviculture attained in any forest.

1. Injury to trees containing merchantable material.
2. Injury to young growth including reproduction.
3. Injury to the soil.
4. Injury to the productive power of the forest.
5. Injury to recreational and scenic values.
6. Injury to wildlife.
7. Injury to forage.
8. Injury consequent upon lessened effectiveness of the forest as a protective agency.
9. Injury to other property.
10. Injury to human life.

Injury to Trees Containing Merchantable Material

The damage may range from slight fire scars at the base to complete consumption of the tree. The latter occurs rarely even in exceptionally severe fires. Frequently large trees are killed outright. Death is caused by the killing of the cambium or living layer between the bark and the wood. Baker (1929) states that a temperature of approximately 54° C. (129.2° F.) is sufficient to kill the cambium, but the more precise studies of Lorenz (1939) would indicate that the lethal temperature lies between 65° and 69° C. (149.0° and 156.2° F.). If the cambium is killed all the way round, the tree is girdled and dies. Dead cambium can usually be told by its dark color in contrast to its light shade when in normal condition. It is not necessary that the bark be burned off or even noticeably charred in thin-barked species to cause death of the tree; heat which scorches the outer bark is often sufficient to kill the cambium.

During the early part of the growing season, when cell division in the cambium layer is at its height, the cambium region is more sensitive to heat than later on in the summer or during the dormant period. Fires occurring early in the growing season are likely to kill a large percentage of the trees in a stand. In the northern part of this country, fires may be listed in decreasing degree of severity as: early spring, late spring, summer, and fall. Where winter fires are possible these are less damaging than those in other seasons.

Power of resistance to fire differs for each species of tree. These differences between species are due primarily to the character and thickness of bark. Layers of cork, which act as nonconductors of heat, are developed to a greater or less extent in the bark. A tree that develops thick corky bark is better protected than one with a thinner and less corky covering. Tree bark may be soft, flaky, and easily inflammable and likely to burn through to the wood underneath, or it may be hard, ignited with difficulty, and rarely burned through. It may also be deeply fissured even at an early age. In other species such breaks in the protective covering of bark do not occur at all or develop only late in life. The anatomical structure of bark not only differs between species but also varies with the same species with age and therefore can affect the resistance to heat. For example, the formation of secondary phellogen and development of layers of dead outer bark make some species more heat resistant than those not developing such tissues.

Moisture content, thermal conductivity, and sensitivity as a consequence of anatomical structure may also differ with species. Stickel

(1941) in experiments with balsam fir, beech, and hemlock found that balsam fir bark offered better protection from heat than beech bark of the same thickness. A 7-inch balsam withstood high temperatures longer than a 12-inch beech. Hemlock has a much thicker layer of dead outer bark than balsam and as a result can withstand heat better than balsam. A 9-inch hemlock is about twice as resistant to fire as a 15-inch balsam.

Old trees of any given species are better protected against fire than the young trees because with age the bark thickens and tends to become more corky. For example, in experiments with Douglas-fir (Hofmann 1924) the cambium in 15-year-old trees with bark ¼ inch thick was killed in 11 minutes by heat of 900° F. applied on the outside of the stem whereas cambium in old trees, protected by bark 4 inches thick, showed no injury from the same heat when applied for a period of 4 hours. Species that secrete resin in the outer bark are very inflammable. Trees that exude pitch as a result of insect attacks are easily injured. Where the pitch is plentiful a fire may run up the tree, killing the cambium on one side for many feet above the ground and leaving a long scar.

On trees where the fire has not burned right through the bark it is difficult (without taking off the bark) to tell to what extent the cambium has been killed. This is a practical problem of great importance in determining whether or not to cut the injured trees after the fire. At least one growing season may be needed to determine whether externally injured trees have been girdled by the fire (Stickel 1935). Several studies have been made with the purpose of correlating the visible outward evidence of the fire with the killing of the cambium. In one investigation (Nelson, Sims, and Abell 1933) the area on the tree trunk discolored by fire was mapped and then stripped of bark, and the area of internal injury was noted. For the average tree satisfactory correlation was found between the areas of external bark discoloration and of internal cambium wounding. Heat resistance was found to vary decidedly between species, yellowpoplar of the five species studied being the most resistant. Such studies are needed for all important species.

A second phase of such studies is to keep trees under observation for a period of at least 10 years and then ascertain the character and extent of injuries that have developed as a consequence of the original fire scars.

In general, conifers suffer more severely from fire than broadleaf

species, although some conifers are exceedingly fire resistant and some broadleaved trees are sensitive to fire.

When heat from a fire reaches the roots of trees, severe injury or death results because tree roots are less thoroughly protected by thick bark than the portions above ground and hence are more sensitive to heat. Trees with shallow root systems suffer more than the deep-rooted species.

Old trees can be found hollowed out at the base by fires. In some trees holes big enough to admit one or more men have been burned out. Such hollows are rarely if ever the work of one fire but represent the effects of several fires. Once the bark has been burned away on one side, succeeding fires burn more readily in the exposed wood. Eventually the tree is burned down or becomes so weakened as to be blown down easily. Since the first log of the tree contains timber of better quality than the upper logs, the injury from hollowed-out butts destroys the best part of the tree.

Killing of portions of the cambium whether in the crown of the tree or near the ground must interfere with the life processes of the tree and unfavorably affect its health. MacKinney (1934) found that repeated partial defoliation by fire slows down the growth of longleaf pine. Although the diameter growth of individual surviving basal-wounded southern Appalachian hardwoods is apparently but little affected, the net growth of stands is reduced materially (Jemison 1944). In this weakened condition the tree is more susceptible to the attacks of insects. Sometimes the insects seem to prefer to enter the tree through the bark covering recent fire wounds (Stickel 1934). Though the fire-injured trees attract bark beetles they may not offer good breeding places because of changed conditions affecting the tree's moisture content. A decided increase of the bark-beetle population on a burned-over area can occur as a result of fire (Furniss 1941). The outcome is increased damage for a few seasons by insects on the burned-over area but not outside the burn. The conclusions reached by Miller and Patterson (1927) for ponderosa pine in California and Oregon were that fires had little permanent effect in increasing losses by bark beetles.

Many fungi find entrance to living trees through wounds. For this purpose fire scars are frequently utilized (Hepting 1935; Boyce 1938, pp. 386–388, 403). Given time enough, the fire-scarred tree is destroyed either through the attacks of insects or fungi or by being burned down by repeated fires.

If trees containing merchantable material are killed outright, they should be cut and utilized before the timber decays or is attacked by

insects infesting dead trees. This is not always possible if the trees are few in number, scattered, or located in inaccessible places. Frequently fire-killed timber can be salvaged for a large percentage of its value before the fire. Burned timber may be valueless a year after the fire, or it may remain sound for several years. Climatic conditions, the species, and the question of whether the bark falls from the trunk soon after the fire are the main factors influencing the length of time during which fire-killed timber remains sound. In a dry climate with a species relatively free from insects and fungi, and under circumstances causing the tree to shed its bark, deterioration is delayed.

It may be advisable to cut merchantable trees injured but not killed outright by fire. Whether it is safe to leave an injured tree and for how long a time cannot be determined without a knowledge of the species, particularly its insect and fungus enemies. The final loss (chargeable to fire) of merchantable material in fire-scarred trees through burning down, decay, and insects frequently exceeds the value of the timber consumed or directly killed by the fire.

Injury to Young Growth Including Reproduction

Trees under merchantable size, and reproduction, with thinner bark and crowns near the ground, are more easily killed and consumed by fire than trees of merchantable size. Even a light fire will kill small seedlings. Where light fires are repeated at intervals of a few years reproduction may be permanently kept out.

Fire acts in the same way on small trees as on large ones but inflicts relatively greater injuries on the small ones.

Even where small trees are only partly girdled by a fire their potential value is greatly reduced. Many years must elapse before the trees are merchantable. During this time insects and fungi have abundant opportunity to enter through the fire scars or elsewhere as a consequence of the weakened condition of the trees and frequently render them worthless by the time merchantable dimensions are attained. Sometimes damage of this character develops so rapidly as to render the trees practically worthless within a year or two after the fire (Stickel 1934; Stickel and Marco 1936).

Injury to the Soil

Forest fires in their action on the soil affect its physical properties more critically than its chemical properties. From the standpoint of

tree growth the physical properties, particularly penetrability and porosity of the soil, are recognized to be of more importance than the chemical characteristics. Physical properties of soils are influenced by fires through decrease in the humus content. Well-decomposed humus is in fact the key to good physical condition of the soil influencing the water relations in the upper soil layers.

Organic matter (humus) incorporated with the soil is not consumed by the heat of the fire. Heyward (1938) has shown that the heat generated by hot forest fires in the longleaf pine region is not great enough to destroy organic matter even so close to the soil surface as ¼ inch.

A severe fire which kills most of the trees opens the forest canopy, burns off the litter, and exposes the soil to the drying influences of sun and wind. The humus in the soil decomposes, and without litter or trees to furnish litter no more humus is formed. The soil on bare burned areas consequently deteriorates in physical condition. Heavy soils become dry, hard, and impervious to water, and often they crack open. Sandy soils become hotter, more porous, and leachy. The colloidal properties of the soil may be slightly injured. The mineral salts left in the wood-ashes are apt to be blown or washed off the surface or leached away through the soil.

On the other hand, fire may be more favorable than unfavorable in its effect on chemical properties of the soil. The effect of fire on chemical properties is likely to be of minor significance as compared to changes in physical properties.

A fire of the lightest type which consumes the litter but does not directly injure the standing trees causes little or no injury to the soil. The loss of the accumulated litter does not prove serious provided a forest canopy exists to provide more litter without delay. In fact, the single fire may occasionally prove beneficial, as indicated on page 28.

The benefit from a single fire is not augmented by repeated ones, however, since the entire humus content is exhausted by such successive fires. On areas rendered barren by a single fire any beneficial effects are purely temporary. Light fires burning over the same ground every year consume the annual leaf-fall and thus keep the ground bare of litter. Under these circumstances, when the humus in the soil is once exhausted the soil deteriorates. Hence, *repeated* light fires seriously injure the soil.

The forest litter contains nutritive materials, principally nitrogen, calcium, phosphorus, and potash. The last three remain in the wood-ashes, but the nitrogen is volatilized and lost to the soil when the forest

litter is consumed by fire. As a consequence, if the forest is destroyed by one fire so that no new litter forms or if fires recur so frequently as to burn up the annual fall of litter, the nitrogen content of the soil becomes impoverished. Long-continued *annual* removal of the forest litter which falls to the ground each year is likely to result in decreased wood production per acre. This decrease may amount to 20 or 30 per cent of the normal growth.

In some places forests are growing with boulders or solid ledges of rock only a few inches below the surface. Here the soil consists largely of organic material and may be completely consumed by a severe fire. The bare rock may be left exposed, the soil having been entirely destroyed.

A soil lacking humus and bare of litter is subject to erosion. This process carries away the upper soil layer, the most fertile portion of the soil. In extreme cases the entire surface layers of soil may be eroded, leaving exposed the subsoil or even the underlying rock. Fires often create conditions favorable for the start and continuance of erosion.

Measurements taken by Hendricks and Johnson (1944) illustrate the losses from soil erosion as a result of fire. The fire in question burning on a steep slope in Arizona destroyed the forest litter, consumed the trees except for blackened trunks, and left the bare mineral soil exposed. Immediately after the fire that occurred in early July, measurements were initiated, and records were kept during the summer. The soil losses during this period, principally in the form of sheet erosion, were equivalent to 32 tons per acre on 43 per cent slopes and increased to 165 tons per acre on 78 per cent slopes.

Injury to the Productive Power of the Forest

Fire injury to the productive power of the forest may be classified as follows:

1. Injury due to replacement of good by poor species.

The composition of a forest type is frequently changed for the worse as a result of fire. Reproduction of a species inferior to those previously occupying the ground may start. Many of the valuable tree species are more sensitive to fire than their associates of less value. It may happen that the fire kills the sensitive species in the existing stand and leaves the resistant, inferior species in possession of the area. It frequently happens that brush and woody shrubs win possession of the area from tree species as a result of fires. In this way millions

of acres of brush fields have been established on lands formerly forested and capable of producing good timber crops. The extensive encroachment of chaparral in the redwood region of California after cutting and repeated burning is an example (Shantz 1947, p. 123).

As a result of fire one forest type may be replaced by some other forest type. For example the birch-aspen types so prevalent in the Northern Forest are temporary fire types created by burns which destroyed more productive stands of spruce, balsam, and northern hardwoods. The light-seeded aspens and birch restocked the burned-over areas, and if other disturbances do not intervene will ultimately be replaced by more shade-enduring conifers and hardwoods. Such radical changes in forest type as a result of fire are not always changes from higher to less productive forest types. The establishment of a pure eastern white pine stand on a burn succeeding a mixed stand of northern hardwoods is a change to a more valuable forest type.

2. Injury due to reduction in the density of stocking.

Sometimes no natural reproduction follows the fire and the burn becomes barren. Most fires, even though they may not destroy the whole stand, at least break the canopy and have the general effect of making the stand more open by reducing the number of trees below the density required for highest quantity and quality production.

3. Injury due to forced cutting or loss of the forest crop before financial maturity.

When a forest crop is killed before the end of the rotation, even though it is cut and salvaged, it may happen that the mean annual growth of the stand in quantity or quality is found to be less than it would have been if the crop had grown to maturity. The productive power of the forest has been decreased in this way.

Injury to Recreational and Scenic Values

The forest as a field for recreation affords exceptional opportunities which are being increasingly developed today. Burned areas are relatively unattractive for recreational use, particularly recent burns. Where recreation is established as an important use of a forest area the injury from fire is not alone to the trees, soil, and productive power as a timber-producing unit, but also to the forest as a recreational asset. Community income from the tourist trade may be unfavorably affected as a consequence of injury to the scenery and recreational facilities caused by forest fires (Stanley 1932).

Injury to Wildlife

Fires, either directly or indirectly, cause the destruction of many birds, other animals, and fish. Many animals are actually burned to death. How destructive to wildlife a single fire can be has been vividly described by Kipp (1931). An indirect effect of fires upon wildlife is the destruction of food and cover upon which animals are dependent. Fires, particularly early spring fires, may have a serious effect upon game reproduction. Habitat conditions for wildlife are changed, often radically, by forest fires. This is likely to have an effect on the succeeding forest, perhaps injurious or possibly beneficial, through change in the biological complex. Thus even though wildlife may escape immediate destruction by fire its development is influenced. Although fire is usually detrimental to the interests of wildlife it is not invariably so, since fire by opening up a dense stand encourages the growth of grass and other herbaceous vegetation, thereby increasing the supply of food.

Injury to Forage

Fires burn readily in dry grass and other plants of forage value. When sufficiently intense, fires tend to kill the roots of such plants, thereby reducing the density of stocking and replacing desirable species by those of inferior value for forage. Serious fire damage to forage can be prevented by grazing so regulated that masses of dry and inflammable forage do not accumulate. In some forest types, inflammable forage is the principal fuel involved in the rapid spread of fires. If the green forage is used by stock, the resource is utilized and the fire danger is reduced also. The beneficial influence of grazing upon fire control is more fully discussed in Chapter 17.

Sometimes a light surface fire is of some value in consuming a mat of dry dead vegetation and in enabling stock to get at the tender green shoots beneath. Occasionally fires are the cause of opening up the forest and bringing in crops of forage plants that under continuous fire exclusion would disappear as tree reproduction becomes reestablished. Consequently, as pointed out under beneficial effects of fire, the livestock interests often favor burning in woodland pasture areas, since thereby the area in trees may ultimately be reduced while the area in lesser vegetation which furnishes forage will be increased.

Injury Consequent upon Lessened Effectiveness of the Forest as a Protective Agency

A well-stocked, properly tended forest may in certain circumstances be a protective agency of tremendous importance. When injured by fire the forest loses its protective capacity to a greater or lesser extent. One of the chief essentials from the protection standpoint is that the forest floor should be well covered with litter or ground cover. These even the lightest forest fire may destroy.

The forest furnishes protection against the start and progress of landslides, avalanches, shifting sands, and erosion. Surface runoff of water is delayed and decreased and stream flow stabilized.

As previously stated, erosion may be a consequence of forest fires. Damage from erosion is felt not only on the lands eroded but also in the lower course of the stream down which the eroded material is transported. River channels and reservoirs are filled with detritus, and deposits of rock and soil are left on lands near the stream. Where the soil deposited is of fine texture and fertile, the lands covered may be benefited. The harmful effects of erosion far outweigh any such advantage. See page 294.

A bare forest prevents the forest from performing its function as a regulator of stream flow. Lacking the sponge-like cover of litter and humus, a bare soil permits rapid runoff of water instead of absorbing it and feeding it out slowly from springs. Floods with their attendant damage are thus heightened and low- and high-water stages made more pronounced.

This fluctuation in water level together with the eroded material in the channel interferes with navigation, often necessitating expensive dredging operations. Power plants and factories relying on water power require a continuous and uniform supply of water rather than one that fluctuates widely in volume.

Injury to Other Property

Buildings, livestock, and property of all kinds are at times threatened by forest fires, and serious losses result. The principal loss is to property found within the forest or in small clearings surrounded by woods. Whole towns have been wiped out by forest fires (Currie 1929; Guthrie 1936).

Injury to Human Life

Rarely, if ever, in the United States does a year pass without loss of human life as a direct consequence of forest fires. The greatest loss of life on record in any one fire took place in the Peshtigo fire of October 1871 in Wisconsin, in which 1500 persons perished (Plummer 1912).

BENEFICIAL EFFECTS OF FIRE

The beneficial effects of fire are summarized in the following paragraphs. In general, a requisite for the use of fire to be really beneficial is exact knowledge of just what conditions are wanted for the accomplishment of some specific purpose and just how the right kind of a fire to create these conditions can be obtained.

1. Fire may be of assistance in establishing natural reproduction of the desired species in a variety of ways. This may be accomplished through the burning of a thick forest litter thereby reducing the depth of the litter, exposing the mineral soil, and thus creating the requisite seedbed condition for some species. Not all species prefer a bare seedbed. Or advance growth of some undesired species may be destroyed so that the desired species can start to grow and gain possession of the area. In establishing longleaf pine reproduction on areas where other species are present a light fire will usually kill these undesired species without injuring the longleaf pine seedlings. For a most excellent historical summary of the development of controlled burning in the management of longleaf pine, the reader is referred to Chapman (1947). The results of 32 years of annual controlled burning in longleaf pine described by Bruce (1947) show that fire permits the development of a fully stocked longleaf pine stand by eliminating the less fire-resistant loblolly and shortleaf pines and hardwood species where these invade the better longleaf pine sites.

The destruction or temporary driving out of seed-eating rodents may prove helpful to reproduction. Unfortunately rodents seem to repopulate a burned-over area within a short time so that little reliance should be placed on a fire for assisting natural reproduction in this way.

Burning of logging slash may enable reproduction to become established on portions of the area so thickly covered with slash as to remain unstocked unless treated.

2. If used just before the planting operation, fire, by consuming the litter and ground cover and by destroying the underbrush, may make

planting easier and cheaper and may increase the percentage of stock that survives the planting. Grassy and brushy areas, when the hindering vegetation is removed, can be more quickly planted. There is less danger that undecomposed organic material will be placed in contact with the roots of the planted stock. The competition of herbaceous and woody vegetation with the planted trees may be reduced, at least for the first season.

3. Fire by burning up deposits of raw humus may improve the physical condition of the soil through better aeration and increase in warmth, and may thus stimulate the growth of the stand. Where deposits of raw humus do not occur, the effect of fire upon the physical properties of the soil will be more harmful than beneficial.

Fires tend to increase bacterial activity in the soil, thereby temporarily stimulating the production of nitrates.

Sometimes beneficial changes in the chemical composition of the soil are claimed as a result of fires. For example, Heyward and Barnette (1934) working with longleaf pine in Florida found a relatively large increase in replaceable calcium and small increases in organic matter and nitrogen associated with repeated fires, while acidity of the soil was consistently less. The increase in calcium and lowering of acidity were attributed to the addition of ash following the fire. Probably other constituents of ash such as potassium, magnesium, and phosphorus are also increased slightly. Heyward and Barnette state that the small increases in organic matter and nitrogen are obtained through the decay of the grass vegetation characterizing burned areas and are to be expected not sooner than 8 to 10 years after a fire.

Possibly the increase of leguminous plants, which often follows a fire, may add to the nitrogen content of the soil through the ability of such plants to obtain nitrogen from the air.

Effects of fire on soil are too complicated and have been studied to such a small extent that improvement in soil conditions in excess of injuries to soil as a result of fire is still debatable and open to question in each individual case.

4. Fire when properly controlled may under certain circumstances prove beneficial to some forms of wildlife. In raising quail and wild turkey in the southeastern states Stoddard (1935) advises the use of controlled fire for the improvement and maintenance of the game range.

5. Forage for domestic animals may be improved by fire. Prescribed burning during the winter season in longleaf pine stands provides more and better forage for cattle than can be obtained on unburned areas

(Lemon 1946). Winter fires, by removing the accumulation of old wiregrass and pine needles, make the fresh forage ready for use a month earlier in the spring and enable the cattle to crop the new growth more easily. Quantity as well as quality of forage is increased. Additional benefits of such prescribed burning are that the seedbed for pine reproduction is improved, the brown spot disease is held in check, the likelihood of damaging fires is lessened, and the forest is kept more open. The question arises in this connection whether a fully stocked stand of timber is wanted and can be maintained on the same areas where an abundant forage crop is produced.

6. Fire may assist in controlling plant diseases. For example longleaf pine seedlings show higher survival and grow faster if areas on which they are growing are lightly burned over every 3 years. The reason is that these fires reduce the activity of the brown spot disease which severely attacks the foliage of longleaf pine (Siggers 1934; Wakeley and Muntz 1947).

Another illustration of the value of fire in plant disease control may be found in the western white pine type. Here the broadcast burning of the area twice in a 3- to 5-year period in overmature stands, and in some mature stands where the western white pine either is of low vigor or where the mixed species are largely defective, has the effect of reducing the *Ribes* population and effectively protecting the young planted stands of pine (Wellner 1946).

7. The intentional, controlled use of fire to prevent the occurrence of a more destructive fire may be beneficial. As usually executed, such use of fire consists in the burning of slash and/or the burning over of all or a part of the area to be protected. Where only part of the area is burned, the burned-over portion ordinarily will be so arranged as to form a system of firebreaks intended to secure maximum reduction of the subsequent fire danger.

Objection may be made to burning over an area simply for the purpose of preventing a worse fire on the grounds that complete exclusion of fire from the area should be attempted and attained (Brown 1947, p. 4). However, there are some forest areas in this country where favorable public sentiment is not sufficiently strong to attain immediately complete exclusion of fire. Here temporarily the use of light, controlled fires may be justified even though the fire may have no other beneficial function. Gorrie (1935) describes such a situation for chir pine forests in India and emphasizes the fact that controlled fires are essential there to prevent the occasional severe fire which otherwise is sure to occur.

Prescribed burning has been developed and used on the Osceola National Forest in Florida (Bickford and Newcomb 1947) for several years to reduce the fire hazard in the longleaf-slash pine type. The authors consider it safe to begin prescribed burning when slash pine is about 6 feet in height and longleaf seedlings are over 1 year in age. Costs of the first 2 years of operation were 6.6 and 7.9 cents per acre. Damage the first year was estimated at 31.4 cents per acre treated and the second year at 8.7 cents per acre. It is estimated that in the future damage can be held to 8 cents per acre.

Frequently properly controlled fire on a given area may prove beneficial in several ways. For example, controlled burning in loblolly pine in the pine-hardwood region of the Southeast (1) prepares a good seedbed for loblolly pine reproduction; (2) as the pine seedlings advance into the sapling stage it keeps down the hardwood associates which threaten to suppress the pine; and (3) it reduces fuel accumulations sufficiently to lessen the danger of severe spring fires (Chapman 1942, pp. 27–31). Similar beneficial effect of controlled burning in the oak-pine stands of south Jersey are emphasized by Little and Moore (1945). In his extensive monograph on longleaf pine, Wahlenberg (1946, p. 164) states that "skillful use of burning for all recognized purposes should reduce the total cost of forest management in the longleaf pine region."

8. Fire may be used to burn down standing snags where this method is cheaper than other ways of accomplishing the result. It is also a standard practice employed for killing bark beetles in badly infested standing trees (Doane et al. 1936, p. 48).

The purposes and methods of prescribed burning as practiced since 1943 on some 300,000 acres of national forest lands in Florida have been summarized in detail by Squires (1947), who while stressing its value as a fire-control measure indicates its usefulness in controlling disease, in protecting wildlife, in improving grazing conditions, in reducing undesirable tree species, and in preparing the site for planting or natural seeding.

The use of fire for thinning stagnating stands of ponderosa pine reproduction has been advised by Weaver (1947). He describes a dense, stagnating, 40-year-old stand of reproduction averaging 12.3 feet in height and 1.7 inches in diameter and a portion of the same stand thinned when about 10 years old by an accidental fire. Here trees averaged 32 feet in height and over 7 inches in diameter breast high. He has successfully used controlled fires for thinning, eliminating chiefly the lower-class trees.

The intentional use of fire for any of the purposes listed above differs radically from the uncontrolled progress of a forest fire. Only when fire is carefully controlled and used with the greatest circumspection to accomplish some definite beneficial purpose, which overbalances the evil effects, is its use in the forest justified.

To emphasize the distinction between the uses of fire for some beneficial purpose and the ordinary forest fire the former are referred to as *controlled* or *prescribed* burning. These terms are defined in *Forestry Terminology* (1944) as follows:

Controlled burning. Any deliberate use of fire on land whereby burning is restricted to a predetermined area and intensity.

Prescribed burning. The application of fire to land under such conditions of weather, soil moisture, time of day, and other factors as presumably will result in the intensity of heat and spread required to accomplish specific silvicultural, wildlife, grazing, or fire-hazard-reduction purposes.

The definitions emphasize the controlled nature of the fire and the existence of definite prescriptions for its use and application.

At the present time fire is not used in an intelligently planned way to the extent warranted by the benefits to be secured. Its intentional use in silvicultural operations is likely to increase after control of carelessly set fires has become more effective. In using fire as a silvicultural tool or for other beneficial purposes great care must be taken not to give grounds for encouraging nonbeneficial fires.

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CHAPTER 4

Character of Forest Fires

CLASSIFICATION OF FIRES

Forest fires may be divided into three classes defined as:

Ground fire which not only consumes all the organic materials of the forest floor, but also burns into the underlying soil itself. Ground fires may be further subdivided into duff fires and peat fires.

Surface fire which runs over the forest floor and burns only the surface litter, the loose debris, and the smaller vegetation.

Crown fire which burns through the tops of living trees, brush, or chaparral.

The basis for this classification of forest fires will be found in the different type of damage and in the different mode of spread and development characteristic of each kind of fire. Often all three kinds of fires burn over a given area before the fire is extinguished.

Forest fires are also classified on the basis of area burned over: Class A fires where the area burned over is ¼ acre or less; Class B fires, ranging from more than ¼ to less than 10 acres in size; Class C fires, which cover 10 acres or more, but less than 100 acres; Class D, a fire of 100 acres or more but less than 300 acres; and Class E a fire of 300 acres or more.

Ground Fires

Ground fires burn in the duff, humus, and peaty layers lying beneath the litter or undecomposed portion of the forest floor. These layers of organic material are either closely compacted or of a fine texture and are shut off from the wind and from the oxygen supply in the air. Consequently a ground fire burns very slowly but persistently

with intense heat and rather uniform destructiveness. Such a fire may burn over several acres in a day or may cover only a fraction of an acre. There may or may not be much smoke, but there is practically no flame.

Duff fires are those ground fires which occur on upland areas where thick deposits of litter, duff, and humus have accumulated. Peat fires include the ground fires which take place on ill-drained areas, such as swamps and bogs, where layers of duff and peat several feet in thickness may have been built up. On account of the depth of the organic material ground fires sometimes appear to burn underground in the soil itself (Ludwig 1923). Actually only the vegetable matter is consumed and the fire is burning above the mineral soil layer or in pockets formed by decaying roots. In some places, particularly on rocky slopes and in swampy areas, the partly decomposed organic matter forms a large part of the top soil zone in which tree roots can develop. Here the ground fire practically destroys the soil and creates a barren area which may require centuries to restock.

The tree roots in ill-drained soils may be located in the layers of duff, humus or peat; and even on well-drained soils an important portion of the feeding roots will be found in or close to the deposits of organic material. The roots are thus easily killed by the ground fire. Ordinarily all trees on the burned-over area are killed by a peat fire through overheating of the roots. Whether this happens as a result of a duff fire depends on the thickness of the organic layers consumed and the depth and character of the mineral soil beneath, encouraging deep or shallow development of the root system.

When the surface is wet (by a light shower or otherwise) but the duff beneath is dry, a ground fire may burn the lower layer of organic material, leaving the surface intact supported by a network of plant roots. The exact location of a fire burning underground, in this way, is difficult to determine. Peat fires may burn for months in swamps temporarily dry. Both peat and duff fires are said to have lasted through an entire winter under a blanket of snow.

Deep deposits of organic material are formed only under conditions which retard normal decomposition. In swamps and lowlands, with excess of water, the organic matter does not readily decay. At high altitudes and in northern latitudes, on account of the cold damp climate, even upland sites may develop thick beds of duff. This is particularly true of conifer stands.

Ground fires are less numerous than surface fires because the material on which they feed dries out less frequently than the top litter.

Furthermore, the sites on which ground fires may occur form a relatively small percentage of the total forest area.

Surface Fires

Surface fires are those which burn on or near the ground in the litter, ground cover, underbrush, and reproduction. They are the commonest kind of fire and occur in all parts of the country.

If only the top of a thick accumulation of duff is dry enough to burn, the fire is classed as a surface fire, whereas, if the entire accumulation of duff were burned, the fire might be classed as a ground fire. Typical surface fires injure the lower part of the trunks of trees beyond the reproduction stage and, if they kill trees, do so by applying heat to this portion of the stem. Much of the fuel upon which surface fires feed is of a light, loose nature and likely to be very inflammable. The fire is so located as to be strongly affected by surface winds and there is an abundant supply of oxygen for purposes of combustion. Hence surface fires are characterized by relatively rapid spread, abundance of flame and heat, but soon die out.

Practically all fires start as surface fires. Given the requisite conditions a ground fire or a crown fire may develop from a surface fire. Dry moss hanging from the trunk or branches, inflammable pitch on the bark, the burning tops of a mass of reproduction, or even the flames from a hot grass fire may serve to carry the fire upward and ignite the crowns.

Crown Fires

Crown fires burn in the crowns of the trees. The foliage at least is consumed and the tree usually is killed through overheating of the cambium. Crown fires are restricted to species which have inflammable foliage. Hence, conifer forests are chiefly affected although there are certain species of broadleaved shrubs and dwarf trees with evergreen foliage of an inflammable character upon which crown fires may feed. In most broadleaved species the foliage, while on the trees, normally remains green, is less inflammable and does not occur in such close arrangement as in conifers. With some broadleaved species the dead leaves remaining for a while on the trees may afford fuel for crown fires. This is more likely to be true in young densely stocked stands than in older stands of broadleaved trees.

Two types of crown fires may be recognized: the running crown fire and the dependent crown fire. The former type progresses independ-

ently through the crowns of the trees. It spreads with great rapidity, though probably no faster than a quick-running grass and brush fire. It is closely followed by a surface fire. The dependent crown fire accompanies a surface fire. The burning material on the ground furnishes the volume of heat which ignites the crowns and maintains the crown fire.

MODE AND RATE OF SPREAD

At first a surface fire burns out from its starting point in circular form, and would so continue were it not for various factors which at once begin to control its development. The wind is of primary importance and soon gives the fire an elliptical shape, the leeward side (the front or head of the fire) progressing most rapidly while the windward side (rear of the fire) burns slowly or dies out. The two sides (or flanks) of the fire, connecting the head and rear of the fire, with a change in wind direction may develop into new heads. Other factors, discussed in the succeeding section, cause radical modification in the progress of the surface fire.

The progress of ground fires is slow and is independent of wind direction or velocity.

Crown fires advance only in the direction of the wind. Burning brands and embers are carried forward by the wind and set other fires in advance of the original one. Thus several fires, both surface and crown, are likely to be burning and may combine. Carried by the wind, a crown fire may leap ahead a quarter of a mile or more, sometimes leaving unburned patches of timber in its wake. This characteristic of crown fires for starting new fires, known as "spot" fires, ahead of the original makes it dangerous to be in the path of a crown fire.

Spot fires may also be associated with surface fires. Independent of prevailing wind conditions, when such a fire becomes large enough, it creates tremendous local convection currents which may pick up embers of any sort—burning pieces of wood, bark, and cones—and carry them first upward and then for various distances away from the fire itself. It may well be said that when a fire is sufficiently large it can create its own wind conditions.

The rate at which forest fires spread may be expressed in various ways. Number of miles per hour at which the fire advances is one mode of expression; acres burned over per hour is another. Still another measure is the length of the perimeter developed in a given

period of time, usually expressed as the rate of perimeter increase in chains per hour. The last is the best way of indicating rate of spread because it shows directly the rate of increase in length of advancing fire edge which must be fought.

Under favorable burning conditions forest fires may make prodigious rates of spread. Show (1936) mentions one fire which, fanned by a high wind, burned over a total area of 23,000 acres in 12 hours or at the rate of more than 1900 acres per hour. Jemison (1932) describes a fire, known as the Freeman Lake (Idaho) fire, which spread at the rate of 1600 acres per hour for 12½ hours. The wind was of only moderate velocity, but the relative humidity was about 10 per cent, the air temperature above 90° F., and the moisture content of the duff less than 10 per cent. One spot fire of 350 acres was started 3 miles ahead of the main fire.

FACTORS INFLUENCING THE SPREAD AND SEVERITY OF FOREST FIRES

Each fire is distinct in its rate of spread and severity from other fires of its type. Nevertheless the factors which govern these all-important components of fire danger are of general application. They must be recognized and the influence of each factor be understood. The most obvious factors controlling the spread and severity of forest fires (once started) are five:

Amount and character of the fuel.
Moisture content of the fuel.
Wind movement.
Topography.
Forest cover.

A variety of climatic factors are basic in determining the moisture content of the fuel. Among such factors precipitation, air temperature, and atmospheric moisture (usually expressed as relative humidity of the air) are primary. Their influence will be brought out as they enter into the discussion.

Amount and Character of the Fuel

Potential fuel in the forest for forest fires is found among the following seven groups.

1. The living trees making up the forest. The living forest together with its underlying soil is what the protectionist attempts to preserve from fire. Generally speaking, its inflammability may be said to vary, in accordance with composition, being usually least in pure hardwood stands and greatest in forests composed entirely of resinous conifers.

2. Underbrush. This is made up of various shrubby plants and of tree reproduction. On the whole it is a living type of fuel and may or may not be of inflammable character. Where made up of evergreen plants it often is quite inflammable. The underbrush may become exceedingly dry in periods of drought. From its position beneath and between the forest trees and because of its height of several feet above the ground, it may, when occurring in thick clumps, easily serve as a means of carrying fire and of igniting the forest itself. Both dead underbrush, killed by the density of the forest, and living plants of an evergreen character are particularly dangerous as means of carrying a severe fire.

3. Living ground cover. The plants composing the ground cover are herbaceous in character (frequently grasses) and have a lighter and more inflammable character than the other living portions of the forest community. These plants are annuals or perennials so that the portions above ground die and dry up each year and consequently become decidedly inflammable. The ground cover, because of its light texture and the thoroughness and speed with which it dries out, may be a dangerous source of spreading fire.

4. Forest litter and undecomposed humus. This consists of the dead organic material, principally leaves and needles, twigs, and other organic residue from the trees. The forest litter and undecomposed humus dry out relatively easily at least on the surface whenever precipitation is scanty or sunlight and winds are prevalent. Because of its continuous extent throughout the forest, it assists the spread of a fire and is particularly important in carrying combustion from dead branchwood to dead branchwood and from log to log.

5. Dead branches and moss on the living trees. Under certain climatic conditions long stringers of moss, which become very inflammable when dry, occur in considerable abundance on standing trees. Dead branches and moss on the trees furnish a means for carrying the fire quickly up the length of the tree. The moss in particular may be a great source of danger in certain forest types.

6. Snags. Under this term are included standing dead trees belonging either to the present forest or relics of former forest generations. Oftentimes these snags are partially decayed and punky with broken,

broomed tops. Snags often carry fire for their entire height and because of the punky material contained may scatter burning brands on unburned areas ahead of the existing fire. They are considered therefore one of the most potentially dangerous types of inflammable material. Owing to their height and consequent exposure to the wind and owing to the fact that most of them are without bark, they dry out very thoroughly and easily ignite. Snags are especially abundant in some of the western conifer forests where they remain standing for decades slowly disintegrating from the top downward.

7. Logging slash. Every logging operation results in leaving on the ground more or less material from the cut trees which cannot be removed profitably. Logging slash is likely to be highly inflammable and often occurs in dense masses, sometimes several feet thick, which cover considerable portions of the cutover area. Logging slash acts both as a source of additional fuel for forest fires and also as an impediment in the way of the fire fighters attempting to build fire lines and control the fire in cutover areas. There is a great variety of material in the logging slash ranging all the way from the small branches coming from the tops of living trees to large-sized cull logs and big tops. While the extent to which logging slash becomes inflammable varies greatly depending on size, species, and climate, it frequently is the primary source of inflammable material on cutover areas.

With such a wide range of material it is evident that there must be an unlimited variability between individual stands as to amount and character of fuel contained and possible rate of spread and severity of the fires which might burn. The critical factor will be the moisture content of the fuel which will now be considered.

Moisture Content of the Fuel

This factor and the amount and character of the fuel are so intimately associated as to merit being discussed together. There can be no fires without fuel to burn, and correlatively there will be no burnable fuel while its moisture content is sufficiently abundant to preclude ignition. Fires are dependent both for their severity and for their rate of spread upon a supply of properly conditioned fuels which not only will ignite but, once ignited, will carry the combustion process forward.

Although theoretically the entire forest is potential fuel, actually a portion only is available as fuel for a forest fire. How large a percentage of the total plant community this portion available for burn-

ing will be at any given moment depends upon the moisture content of the fuel, which is the factor of primary importance in determining relative fuel inflammability. Abundant and uniformly distributed precipitation will maintain such a high moisture content in all potential fuel that fires cannot run. There may be thousands of cubic feet of wood and other vegetable products on every acre and yet not a single cubic foot of fuel available for a fire because of high moisture content. Unfortunately in most forest types such a condition does not prevail throughout the year.

The volume of potential fuel remains relatively the same for long periods, changing only as the result of growth, mortality, or cutting of the immediate forest vegetation. But the moisture content of the potentially inflammable material fluctuates from season to season, day to day, and even hour by hour. Thus within the same forest stand the fuel available for burning will be a changeable quantity and will vary in character depending upon the scarcity of moisture. In seasons of low precipitation the quantity available increases and rises rapidly with a lengthening of a drought.

Obviously the weather exerts a controlling influence on the moisture content of forest fuels. Precipitation itself is the chief weather factor influencing fuel moisture content over protracted periods. It is also the only weather element that can bring about the cessation of fire danger. The effectiveness of a given amount of precipitation in this connection, however, varies with the season of the year. Mitchell (1926) has found that in Minnesota summer precipitation amounting to less than 0.5 inch in 10 days has apparently little effect in keeping fires down, whereas in the fall 0.5 inch in a 10-day period is highly effective.

As a weather factor secondary to precipitation, but especially important in affecting fuel moisture content during dry periods, atmospheric moisture usually expressed as relative humidity (of the air) must be recognized (Hofmann and Osborne 1923). Relative humidity is the ratio of the actual mass of water vapor per unit of volume to the mass of water vapor that would saturate that volume at the same temperature and pressure, or roughly the percentage saturation of the air. Changes in relative humidity are brought about in one of two ways: (1) by changes in temperatures, for warm air holds more moisture than cold air—at 90° F. 1 cubic foot of air holds twice as much moisture as at 68° F.—and (2) by changes in amount of moisture in the air. Air temperatures and wind are weather factors which exert

an influence upon relative humidity and hence affect fuel inflammability.

Certain parts of the forest, such as the living trees and shrubs, rarely if ever dry out sufficiently to burn readily. Green foliage unless of a resinous nature burns with difficulty even in protracted dry periods. The litter composed of fallen leaves and twigs dries quickly and is easily kindled by a spark. Conifer needles, if dry and not compacted, burn faster and create a hotter fire than the litter from broadleaved trees. Grasses and other herbaceous vegetation become as dry as tinder at certain times of the year at which time they burn more rapidly than either conifer needles or hardwood leaves. During extended droughts, the humus and even deep peaty deposits in swamps may become thoroughly dry. Large limbs and dead trees do not dry out as quickly as the litter but ultimately may attain an exceedingly dry condition. This is particularly true with standing dead trees from which the bark has disappeared.

The material which makes possible the start and quick spread of a fire is the fuel of a light, loose character, such as the top litter, herbaceous vegetation, dry moss, resinous needles, and the outer surface of the more solid material. Exposure to the air with its plentiful supply of oxygen enables combustion to progress rapidly once such fuels have been ignited. The moisture content of this class of material is subject to rapid and large daily fluctuations, because it is easily influenced by changes in the weather especially by the diurnal variations in air temperature and relative humidity. Moisture may be either evaporated from the fuel into the air or absorbed by the fuel from the air, as the relative humidity falls or rises. Since the air can hold more moisture when warm than when cold, a rise in air temperature when the atmosphere is drier than the fuels causes evaporation of moisture from the fuel into the air; under reversed atmospheric moisture—fuel moisture conditions, a fall in temperature has the opposite effect. Under normal conditions the fuel in the forest is likely to absorb at night slightly less than the amount of moisture that is evaporated during the day time.

The all-important relationship between weather and forest fire danger has led to many investigations (Wright and Beall 1945) having for their primary purpose the improvement of fire control through developing accurate methods of measuring current fire danger and using such estimates in conjunction with weather forecasts to predict the probable future fire danger. Such forest fire weather studies as reported on by Gisborne (1928) and Stickel (1931) have shown that

fuel moisture content is the best index to forest inflammability. Generally speaking, forest fuels containing more than 30 per cent moisture are relatively safe from ignition by all ordinary firebrands such as camp fires, matches, smokers' materials, and locomotive sparks. As fuel moisture content decreases below this level an increasing number of these causes of fires become effective until at around 6 per cent moisture content or less all sources of ignition are dangerous. Relative degrees of inflammability based upon differences in the moisture content of forest fuels have thus been established.

Forest fire weather studies likewise have shown that, in addition to relative humidity, the moisture content of forest fuels and hence the degree of inflammability is controlled by other weather elements or conditions such as air and duff temperatures, depression of the dew point, and number of hours since the last precipitation. These are readily measured and can be used to estimate fuel moisture content. None of these are as accurate for this purpose as is evaporation which is in effect a summation of all the weather elements (Stickel 1931; Jemison 1935).

The moisture content of fuels especially those in immediate contact with the mineral soil may be influenced by soil moisture which in turn is affected by the height of the ground water table. The level of water in the ground falls in seasons of drought, and greater dryness of the fuels may be expected in such periods. For this reason ground water level movements have been suggested as an indicator of forest fire weather conditions (Thompson 1927).

Although fuel moisture content may be determined with a fair degree of accuracy by weather measurements alone, they have not proved equally satisfactory for all types of forest fuels, particularly the heavier classes of materials like dead branchwood, snags, and thick duff layers. These denser, slower-drying fuels when once ignited present greater problems of control than fire in faster-drying light fuels such as dead grass and thin leaf litter. For this reason direct methods of measuring fuel moisture content have been developed making use of such devices as the duff hygrometer and fuel-moisture-indicator sticks (Gisborne 1936, pp. 30–35). The use of such data and other associated variables of fire danger for determining daily variations in forest fire intensity are fully discussed later (Chapter 11, Fire-Danger Rating).

The severity of a fire is more directly dependent upon the amount of available fuel than is the rate of spread. A fire may run rapidly

under certain conditions even if the fuel supply is scanty, but such a fire cannot be a severe and damaging one.

When there is a large accumulation of dry fuel the fire becomes truly a conflagration. A forest fire itself acts as a drying agent, reducing the moisture of the fuel which lies within range of the heat developed. If once a large volume of heat can be created, the fire gathers momentum and progressively dries the fuel for its own advance. This explains why slash-covered areas with large accumulations of dry fuel may be a menace to adjoining green timber.

Forest fuels must be heated to temperatures of 600° to 800° F. before they will burn (Osborne 1942, p. 6). When the moisture content is high a great deal of heat is used in evaporating the water, which must be accomplished before the material will ignite. There may not be enough heat remaining to keep the temperature above the kindling point. If not, the fire is extinguished. To illustrate the amount of evaporation necessary before combustion can occur, figures secured by Hofmann (1924, p. 52) for Douglas-fir stands are summarized below:

Gallons of Water Evaporated per Acre before Needles Ignited	By
3900	A 12-year-old stand of 8000 trees per acre
2300	A 12-year-old stand of 20,000 trees per acre
1500	A mature stand of 32 trees per acre

Evidently it would require much more heat to start and maintain a crown fire in a young than in an old Douglas-fir stand.

Not only does the green foliage ignite with difficulty because, as just described, it has to be dried out before combustion can take place, but also, particularly in hardwood stands, it affects the inflammability of other fuel favorably by increasing atmospheric humidity. This is discussed in a later section of this chapter in which the influences of the forest cover upon fire danger are considered.

The uniformity and compact arrangement of the inflammable material have a great influence on the spread and severity of the fire. The fastest spread occurs when the material is easily inflammable and arranged uniformly so that the fire suffers no check but not so compactly as to prevent the ready access of air.

The severity of a fire, other conditions being equal, increases with the density of the material. Density makes for a slow advance of the fire and keeps the fire in one place for a relatively long time. This

results in more complete consumption of the material and, therefore, greater injury. For example, a fire burning through a field of scrub-oak brush covered with dry leaves will rush forward rapidly; but much material will be unconsumed, and injuries to standing trees may be slight because the flames, though hot, do not remain long in one spot. If this same brush is cut and left lying in an evenly distributed compact layer on the ground and then burned at the same degree of dryness as when standing, the fire will advance more slowly, consumption of the material will be more complete, and injury to the living trees will be greater.

A ground fire burning in finely powdered humus with a restricted oxygen supply necessarily burns slowly, but all dry material can be reached and consumed, and all trees affected are killed. A crown fire burning in the tree tops where the individual limbs and trees are frequently not touching requires a wind to carry the flames from point to point and dry, easily ignitable material upon which to feed.

Wind Movement

The wind determines the general direction in which surface and crown fires advance. Given the same fuel, moisture content, and topographic conditions, the rate of spread of these fires increases with the velocity of the wind (Curry and Fons 1938). However, fuel moisture content which controls fuel inflammability is more important in determining the severity of burning conditions than is the wind velocity. When fuels are thoroughly saturated with moisture there can be no fires even though the wind velocity is high, yet on a day without winds if fuel moisture content is low fires may start and spread.

A dangerous combination is a strong wind blowing from a dry region. The dreaded "Santa Ana" or northerly to easterly winds blowing across the southern California forest each fall is an excellent illustration (Show et al. 1941, p. 47). This brings in dry air and changes the absolute humidity of the air. The effect is to lower the relative humidity, increase evaporation, and hence lower the moisture content of the light-weight fuel especially. Under these conditions when once a fire is started the wind assists in more thoroughly drying out the fuel ahead of the fire, both by increasing evaporation through the new air supply brought in and by driving the heated air, out of its normal upward direction, horizontally into contact with new fuel as yet not ignited.

A steady wind is required to carry the heat from tree to tree in a

running crown fire. Otherwise when the wind slackens the fire dies down in the tops and burns as a surface fire.

The fire itself creates a draft upward because of the tendency of hot air to rise. Such an air current may pick up burning material and carry it forward to start new fires. On slopes the upward movement of the hot air tends to increase the speed and severity of the fire.

Topography

Altitude, aspect, slope, and surface conditions each affect spread and severity of the fire. In a rugged country, owing to the frequent and wide variations in topography, the progress of a fire is irregular. Regions without distinguishing topographic features favor a more uniform development of all sections of the fire.

As demonstrated by Hayes (1941) altitude and aspect are important controlling variables of fire behavior through their influence on fuel moisture content and the weather factors controlling it. From measurements made at a series of paired fire-weather stations on north and south aspects at elevations ranging up to 5500 feet in northern Idaho it was shown that distinct altitudinal zones occur with a thermal belt midway between the lowest and the highest zones. During night periods burning conditions are most critical in the thermal belt on both aspects studied because of the centering in this belt of the inversion of the vertical gradients of most of the fire-danger factors save wind velocity. On south aspects during day periods fire behavior was found to be somewhat more dangerous in the thermal belt than above or below it, while on the north aspects for the same period the highest altitudinal zone was most critical.

By means of an "artificial sun" apparatus Byram and Jemison (1943) have investigated the influence of solar radiation on forest fuel moisture. From this study they have derived formulae which can be used to prepare fuel moisture equilibrium maps showing variations in fuel inflammability with aspect and slope that result from differences in radiation intensity alone.

A fire burning uphill advances rapidly. The heated air rising vertically and radiating horizontally passes near (particularly on very steep slopes) the ground ahead of the fire and by its heating and drying action hastens ignition and increases the intensity of the fire. Trees are injured worst on their uphill sides, both because humus and litter tend to accumulate there, and because the flames protected by the tree trunks from the draft burn longer in proximity to the tree. When a

fire runs up a slope to the summit of a narrow ridge, burning brands are likely to be carried over the ridge and dropped farther ahead than on level ground. Fire progresses downhill very slowly and relatively feebly, burning as it must against the upward rising draft of heated air. Where the available fuel is of such a character as to roll downhill easily (sticks, cones, or fragments of rotten logs and snags), these burning embers may start fires some distance below the original fire. Fires so set are likely to sweep up the slope quickly until they meet the other fire. Cones furnish the most dangerous material for carrying fire down a slope.

Where slopes become precipitous and barren of vegetation they form effective barriers to the spread of fire. A stream or a narrow strip of moist ground at the bottom of a ravine may serve to stop a fire. The fire has burned slowly down the slope and on approaching the stream has not sufficient momentum to leap this obstacle. Fires on slopes with northern or eastern aspects do not spread as rapidly as those with southern or western exposures. This is explained by the greater dryness of the fuels, since south slopes are longer exposed to the heat of the sun.

A smooth surface on which the inflammable material occurs uniformly distributed tends to make the fire burn more evenly and intensely. Bare rocks function to delay and break up the front of the fire.

Forest Cover

Plant ecologists have long recognized that forest vegetation exerts a marked effect on the microclimate of an area. Through the leafy canopy it intercepts solar radiation thereby lowering the air and duff temperature as well as effecting a higher relative humidity of the forest atmosphere. Both the crowns and stems of the trees act as barriers to the free sweep of air currents thereby greatly reducing the wind velocity. Together such ameliorating influences bring about lower evaporation within the forest, a fact that has a pronounced effect on the rate at which forest fuels dry out (Gisborne 1928; Stickel 1931).

To the above must be added the role played by the physiological life processes of trees, particularly the favorable increase in atmospheric humidity by increased transpiration. Wright and Beall (1934) attribute the decrease in fire danger which comes after the hardwood foliage develops in the spring at least in part to transpiration into the atmosphere by new tree foliage.

From such fire-weather studies as have been made by Gast and

Stickel (1929), Stickel (1933), and Jemison (1934) it is evident that silvicultural practices may contribute in no small degree to increasing local fire danger. Jemison states, for example, that a full forest cover in Idaho eliminates 90 per cent of the critical fire days during the height of the fire season. Any form of cutting which greatly reduces the amount of forest cover increases the exposure of fuels to the desiccating action of all the weather elements. This results in a proportional increase in the fire danger in intensity as well as in duration. The forester should recognize the important effect of varying canopy density upon fuel inflammability in fire-control planning.

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CHAPTER 5

Causes of Forest Fires

It is a matter of utmost importance that the causes of forest fires should be known. This information is wanted not primarily for historical or descriptive purposes but for practical use in planning fire prevention for the elimination of each source of fire. Before fire prevention can be intelligently pursued, the causative agencies responsible for starting fires must be identified and located.

The causes responsible for the origin of forest fires are numerous and of widely varying character. They admit of grouping under a relatively small number of types and are usually arranged under eight headings. This furnishes a sufficiently detailed classification for statistical purposes and is broad enough to fit conditions in all parts of the country. It is an advantage to have fire causes grouped in the same way for all parts of the country.

The U. S. Forest Service, assisted by various cooperating agencies, each year gathers and publishes statistics concerning fire causes and other fire data. The grouping of fire causes and the gathering of fire cause data throughout the country have become standardized in this way. The classification of fire causes here presented shows the grouping now recommended and used by most fire control organizations (*Forestry Terminology* 1944:31). Further subdivision, if it appears desirable, can be introduced without changing this major grouping.

The classification of fire causes is as follows:

Camp Fire. Forest fires resulting from fires started for the purpose of cooking, or providing light or warmth, by persons camping or traveling on or near wild land, except those started by railroad or lumbering employees in connection with their duties.

Debris Burning. Forest fires resulting from any fires originally set for clearing land for any purpose, or for rubbish, garbage, range, stubble, or meadow burning,

without intent on the part of the burner to have such fires spread to lands not intended to be burned. (This cause does not include lumbering fires or hazard reduction on rights-of-way of common-carrier railroads.)

Incendiary. Forest fires which in the judgment of the reporting officer are deliberately set by anyone with the intention of burning over land or damaging property not owned or controlled by him.

Lightning. Forest fires caused directly or indirectly by lightning.

Lumbering. Forest fires, except those caused by smokers, resulting from lumbering operations. (Lumbering operations include all activities connected with the harvesting or processing of wood for use or sale. Lumbering fires will include those caused by logging railroads which are not common carriers.)

Railroad. Forest fires resulting from maintenance of rights-of-way or construction or operation of common-carrier railroads.

Smoker. Forest fires caused by smokers' matches or by burning tobacco in any form.

Miscellaneous. Forest fires which properly cannot be classified under any of the foregoing seven standard causes. (Fires of unknown origin should be classified under most probable cause and not under Miscellaneous.)

A ninth heading "unknown" is added by some organizations to include the fires which cannot be assigned definitely to any known cause. Under conditions which prevail at present, many fires are classed as of unknown origin. With improvement in fire protective organizations the percentage of fires classed as of unknown origin should steadily diminish. As long as the fires of unknown origin form a relatively large percentage of the total number of fires it is difficult to evaluate correctly the comparative importance of the other fire causes. Although the system adopted by the U. S. Forest Service for use on the national forests of assigning the fires of unknown origin to the probable cause is the best way out of the difficulty, it has a tendency to distort the reliability of reported causes between adjacent states when one recognizes unknown-caused fires and the other does not. For this reason, even where the social pattern and forest types of neighboring states are practically identical, it is not at all uncommon to have, for example, apparently great differences with respect to the number of fires caused by smokers and incendiarism.

Another way of handling the fires of unknown origin in order to secure the right perspective is to prorate them among the known causes. Mitchell (1927) employed this method in analyzing fires in Minnesota, allotting the unknown causes on a prorata basis to all the other known causes except railroads. Railroads were excluded from this allotment because fires originating from railroads are more easily assigned to their origin than those originating from other causes.

Statistics on causes are gathered by private, state, and federal or-

ganizations which provide fire protection and are compiled and published by the U. S. Forest Service. These statistics have been drawn upon in compiling the table which illustrates the relative importance of the various fire causes throughout the country.

CAUSES OF FIRES OCCURRING ON PROTECTED LANDS IN THE UNITED STATES (EXCLUSIVE OF ALASKA) ON FEDERAL LANDS AND ON STATE AND PRIVATE LAND EXPRESSED IN PERCENTAGE OF THE TOTAL NUMBER OF FIRES [1]

Cause	Federal Lands		State and Private Lands		All Lands, 1946
	Average for the Years				
	1932–1936	1942–1946	1932–1936	1942–1946	
Lightning	47.5	51.3	2.7	2.9	8.8
Railroads	1.0	2.4	4.6	7.8	6.6
Camp fires	9.1	4.5	6.5	4.0	4.4
Smoker	19.0	15.1	25.3	23.7	23.9
Debris burning	5.5	3.3	14.2	16.8	15.5
Incendiary	12.0	15.4	27.5	28.3	25.6
Lumbering	1.0	0.7	1.6	1.9	1.6
Miscellaneous	4.0	6.6	9.8	12.2	13.6
Unknown	0.9	0.7	7.8	2.4	0.0 [2]
Total	100.0	100.0	100.0	100.0	100.0

[1] Obtained from the fire cause statistics published annually by the U. S. Forest Service.

[2] Less than 0.1 per cent.

These eight major classes of fire causes may be divided into two groups, natural and man-caused. The former group is nonpreventable and includes lightning fires and those set by spontaneous combustion (listed under fires of miscellaneous origin). All other fires, approximately 90 per cent of the total, are man-caused and consequently preventable. Evidently man is the chief cause of forest fires. Fundamentally, carelessness is the underlying cause of fires. This is a common fault of the American people, in fact of all mankind. The greatest proportion of all man-caused fires may be traced back to carelessness.

In the foregoing table, fires on federal lands have been kept separate

from those on state and private lands and the causes are shown for the 5-year period 1942–1946 and for a corresponding 5-year period 10 years earlier.

The most striking contrast between the causes of fires on federal lands and those on state and private lands is the prominence which lightning fires assume on federal lands. Approximately 50 per cent of all fires on these lands are set by lightning as compared to less than 3 per cent originating from this cause on other lands. The primary reason for this difference is that the forests in regions climatically most subject to lightning fires are largely federal owned.

The three principal causes of fires for the United States as a whole are incendiarism, smokers, and debris burning, as shown in the last column of the table. Together these three causes make up over 60 per cent of the forest fires. Lightning comes no higher than fourth place for the entire country. There appears to be no significant change between the earlier and later periods as regards the relative importance of fire causes.

The distribution of fire causes is not uniform, as can be easily seen from inspection of the percentage figures given in the table on page 55. What evidently applies to the individual states as shown by these data applies with even greater force as smaller and smaller land units are considered.

Causes may show marked variations between forest areas quite close together and even on different parts of the same forest. Hence studies of fire causes should be local in character, and the statistics should be obtained separately for each forest unit.

Fire causes may change with time. Economic developments affecting a forest area may increase the importance of some fire causes and decrease that of others. The season of the year influences the type of fire-causing activity which is operative.

Holidays and Sundays as contrasted to other week days may influence the number of fires set by a given cause. Wilkinson (1940) showed that in the Pacific Northwest there were 1.7 times as many fires per day on Sunday as on other days. Holidays gave nearly as high an average as Sundays. The presence in the forest of many more people than on other days makes such increase in fires understandable.

Data for the year 1946 from a few individual states are presented in the table on page 55 to show how the relative importance of fire causes changes, depending upon the region. These states have been selected because of having the highest percentage for some one or more

fire causes of any of the states. The highest percentage figure for each of the fire causes is italicized in the table.

Arizona had the highest (82.9) percentage of lightning fires. Wisconsin reports 28.1 per cent of its fires due to railroads—a larger proportion than in any other state. The high record for camp fires goes to Colorado, nearly a quarter of all its fires being of this origin. Smoker fires constitute 55.2 per cent of the total in New Jersey. In Illinois more than 39 per cent of the fires are due to debris burning; in Oklahoma nearly 80 per cent are started by incendiaries. Maine with 7.8 per cent has the largest proportion of lumbering fires. Miscellaneous fires comprise 53.3 per cent of the total number in Rhode Island. Recording such a large percentage of the fires as of "miscellaneous" origin is an indication of inaccurate gathering of fire cause data.

Causes of Fires in Selected States Expressed in Percentage of the Total Number of Fires, 1946 [1]

Cause	Arizona	Wisconsin	Colorado	New Jersey	Illinois	Oklahoma	Maine	Rhode Island
Lightning	*82.9*	1.0	39.2	0.0 [2]	0.0 [2]	2.5	4.9	0.0 [2]
Railroads	0.2	*28.1*	5.6	21.4	6.3	1.1	2.9	1.0
Camp fires	4.2	2.8	*24.5*	1.1	3.3	2.9	10.4	1.0
Smoker	8.8	28.7	12.7	*55.2*	24.8	9.7	37.6	15.4
Debris burning	0.6	16.7	1.7	8.5	*39.2*	1.3	13.5	15.2
Incendiary	0.7	10.8	0.3	10.8	6.9	*79.5*	2.0	13.6
Lumbering	0.4	0.9	1.4	0.0 [2]	1.2	1.3	*7.8*	0.5
Miscellaneous	2.2	11.0	14.6	3.0	18.3	1.7	20.9	*53.3*
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] Data obtained from the fire cause statistics published by the U. S. Forest Service.
[2] None or less than 0.1 per cent.

The importance of fire causes should not be judged alone by number of fires started but should be evaluated also according to the area burned over and by the loss resulting. The table on page 56, compiled from published statistics, shows in parallel columns the percentages of fires attributable to each cause when each of the three measures mentioned above is applied separately and finally when the three are combined. From this table it will be seen (on the basis of the 1926–1930 period for which damage figures separated by causes are available) that incendiary fires are the worst in total acreage burned over and in damage caused although fewer in number than smoker fires. Smoker fires though more numerous are less destructive in acreage burned and damage done than are incendiary fires. This is logical since

AVERAGE ANNUAL CAUSES OF FIRE [1] ON PROTECTED AREAS IN THE UNITED STATES (EXCLUSIVE OF ALASKA) FOR THE 5 YEARS 1926–1930 [2] EXPRESSED IN PERCENTAGE OF NUMBER OF FIRES, ACREAGE BURNED OVER, AND TANGIBLE DAMAGE

Cause	Number of Fires	Acreage Burned Over	Tangible Damage	All Three Combined
Lightning	9.5	6.2	12.3	9.4
Railroads	9.1	4.1	6.0	6.4
Camp fires	7.9	6.3	4.2	6.1
Smoker	21.1	16.0	14.4	17.2
Debris burning	12.5	12.5	9.0	11.3
Incendiary	17.1	29.5	22.8	23.1
Lumbering	3.9	5.0	9.2	6.0
Miscellaneous	9.2	10.0	10.4	9.9
Unknown	9.7	10.4	11.7	10.6
Total	100.0	100.0	100.0	100.0

[1] Data obtained from the fire cause statistics published annually by the U. S. Forest Service.

[2] The present day annual summaries of forest fire statistics do not permit bringing this table up to date.

the incendiary often picks the most dangerous time and relatively inaccessible locations for setting fires whereas smokers' fires occur chiefly in places easy to reach and at all times during the fire season. The final rating (last column of the table) lists the four most dangerous causes for the country as a whole as incendiary, smoker, debris burning, and lightning, in the order named. Miscellaneous fires are not considered in this rating since they comprise a variety of minor causes. Unknown fires are also omitted since they should be divided among the other causes.

When more local distribution than that afforded by state boundaries is studied, it is found that fire causes often have quite distinctive zones of occurrence and sometimes are seasonal in character.

Lightning being a natural fire cause and in itself a weather factor is extremely seasonal, operating only at irregular intervals during the time of year when lightning storms develop. It is likely to be a major fire cause in regions subject to frequent severe lightning storms and having a relatively dry summer climate. If abundant precipitation accompanies the lightning, or if precipitation is ample between lightning storms, few if any fires will originate from this source. The right climatic conditions as regards a dry summer are met in parts of the Rocky Mountains and Pacific Coast states. As a consequence, it is in these states that lightning fires assume greatest importance. Statistics

for 1946 indicate that lightning is the chief cause of forest fires in ten states, namely, Arizona, Colorado, Idaho, Montana, New Mexico, Oregon, South Dakota, Utah, Washington, and Wyoming.

There is a difference in the character of lightning storms. Some storms cause relatively few fires, even in a region with suitably dry summer climate; other storms set numerous fires. The amount of precipitation accompanying the storm, both before the lightning flashes and subsequent to the lightning, influences the setting of fires. Fewer fires are set if the accompanying precipitation is considerable. The direction of the lightning flashes, whether from cloud to ground, from ground to cloud, or from cloud to cloud, is important. The lightning passing from cloud to ground is largely responsible for setting forest fires.

Even in these climatically suited regions there are distinct zones within which lightning storms are frequent. The number of fires set by lightning, other conditions being equal, increases with the number of storms. In a bad lightning storm a large number of fires may be set in a single day, frequently in inaccessible places. In some parts of the West these lightning zones have been mapped on the basis either of number of lightning fires which have been started or of number of lightning storms which have occurred.

Show and Kotok (1923) mapped lightning fire, camp fire, and incendiary fire zones in the California national forests and also showed in graphic form the seasonal occurrence by months of fires originating from a variety of causes. Distinct differences in seasonal occurrence were found for the various causes. Debris burning had the nearest uniform distribution throughout the year while lightning showed the highest concentration. Morris (1934) found that in the forests of Oregon and Washington the average number of lightning storms per 100,000 acres could be mapped in zones but that less satisfactory results were obtained when attempt was made to zone the number of lightning fires per unit of area.

Railroads become a prominent fire cause in regions where their tracks with many grades and cuts are bordered by woodland. The character of fuel burned, the density of rail traffic, the degree to which spark arresters, ashpans, and rights-of-way are kept in efficient condition for protection are influencing factors. In general, combinations resulting in a high percentage of railroad fires occur in the northern half of the territory east of the Mississippi; particularly in the Lake states, the northeastern, the Middle Atlantic, and the southeastern states along the Atlantic Coast.

Fires set by campers are scattered along lines of travel including roads, trails, and streams. There is usually a definite zonation for this class of fires and a period of occurrence in which local hunting and fishing seasons are a determining factor.

The increase in the relative importance of smoker fires that has taken place quite generally over the country may be attributed to the increasing use of the forest, thus raising the risk from smokers, and to the fact that the prevention of fires from this cause is more difficult than from some other causes. It may well be that the percentage of smoker fires may rise as a result of decreases in other causes. Smoker fires may occur wherever people go in the forest but are mainly restricted to accessible portions. Twenty-seven states attributed more than 20 per cent of their fires to smokers.

Regions where land clearing is in progress or forest areas are interspersed with agricultural land show the highest percentage of debris-burning fires.

Incendiary fires attain greatest relative importance in sections where the local inhabitants believe that they are benefited in one way or another by forest fires. Oftentimes this is the fact, at least so far as temporary improvement in conditions is concerned. Alleged benefits may include improvement in forage or huckleberry crops, driving away snakes, creating less favorable conditions for dangerous animals, uncovering minerals for prospecting, and creation of a firebreak surrounding valuable property which needs protection. Desire for revenge, the excitement of seeing fire burn and of watching the firefighting, attempts to cover evidence of trespass or other crime, or attempts to obtain a firefighting job are all motives which may actuate an incendiary. Scattered communities anywhere in the country may suffer from an abnormally high number of such fires, but on the whole the southern states are more likely to have incendiarism as a major cause.

Lumbering is a minor cause restricted to areas where lumbering operations are being conducted. Miscellaneous fires are of secondary or minor importance in nearly all regions.

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CHAPTER 6

Fire Prevention

WHAT FIRE CONTROL INCLUDES

Under the subject of fire control are included not alone the actual suppression of burning forest fires, but also prevention of the start of fires plus all activities, carried on prior to suppression, directed toward reduction of the fire danger and toward effective suppression of fires. For the purposes of this discussion fire control will be considered under its three main subdivisions, namely:

1. Fire prevention comprising those fire-control activities concerned with the attempt to reduce the number of fires through education, hazard reduction, and law enforcement.
2. Presuppression activities in fire control are concerned with the organization, training, instruction, and management of the fire-control organization, and with the inspection and maintenance of fire-control improvements, equipment, and supplies to insure effective fire suppression.
3. Fire suppression covering all the work of extinguishing a fire after its detection.

The extent to which each of the three branches of fire control is developed and intensified in its application depends upon the fire danger in a given forested area. In some places fire control is a relatively simple problem which calls for no elaborate planning or complicated application. At the other end of the scale are those forest regions where the fire danger is so great that the most intensive planning for and execution of fire prevention and presuppression action are demanded and a carefully thought-out technique for suppressing fires must be promptly and accurately applied if the forest is to be saved. The practitioner must judge for his forest what degree of concentration on fire control is appropriate.

Fire danger is the resultant of both constant and variable factors that determines whether fires will start, spread, and do damage, and determines as well the difficulty of control. *Constant factors* are those which are relatively unchanging, e.g., normal risk of ignition, topography, all fuels, and exposure to prevailing wind. *Variable factors* are those which change from day to day, season to season, and year to year, e.g., all weather elements, fuel moisture content, and variable risks of ignition. Fire danger covers both risk, e.g., the chance or probability of fire starting, and hazard, a term applied to fuels that form a threat either of special suppression difficulty if ignited or of probable ignition because of their location.

PRINCIPLES OF PREVENTION

If the start of fires could be prevented, all injuries from fire and all costs of fire suppression and the elaborate preparations made to be ready to control the fires which start could be saved. Complete prevention is an unattainable goal. Fires originating from lightning and spontaneous combustion are unpreventable and must always be taken into the reckoning. Fires originating from other causes are due to man and in theory are preventable. From the practical standpoint it will never be possible entirely to prevent man-caused forest fires. The experience in building fires over many decades proves this point. Even today a large proportion of all building fires are attributed to preventable causes, resting in the last analysis upon human carelessness or intention.

Since, as shown in Chapter 5, preventable forest fires amount to approximately 90 per cent of the total number of fires there is evidently abundant opportunity for a substantial reduction.

Fire prevention strictly speaking covers the elimination of man-caused fires or, as it works out in practice, the reduction in number of such fires.

However, there has been included under prevention the additional task of reducing the potential danger of serious fires caused by the presence of large volumes of inflammable debris (Anonymous 1937, p. 142). It is open to argument whether the reduction of physical hazards involved by the presence of inflammable debris rightly belongs under prevention rather than under presuppression activities. Admittedly, action to reduce the physical hazards is often an essential step if serious fires are to be avoided. Prevention, however, is best construed in its narrower meaning which confines it to the reduction of the

number of man-caused fires. Only as far as lessening the physical hazard reduces the number of man-caused fires, rather than decreases the seriousness of these fires, is such reduction of physical hazards properly a function of prevention. In some places, such as around camp grounds or on railroad rights-of-way, reduction of inflammable material may be so complete that no fire can start on the areas treated, but on the majority of sites a light fire is still possible after the inflammable debris has been reduced in volume. Reduction of inflammable debris will be discussed under presuppression in Chapter 10.

Only a beginning has been made in the field of fire prevention as compared with the possibilities for accomplishment. It is now recognized that expenditures of time and money in prevention activities may be reflected in substantial saving in the costs of fire suppression and in areas burned over.

Prevention is essentially a long-time activity that should be cumulative in its effects over the years. This is true even though substantial results may quickly follow a single prevention project.

Two general lines of approach are available in fire prevention, both directed against the principal setter of forest fires, namely, man.

1. Education of the people concerning forest fires.
2. Enforcement of the laws relating to forest fires and enactment of new laws where needed.

Summed up in a sentence, man-caused fires will be prevented in any region to a degree commensurate with the knowledge of its people as to the loss accruing to them directly or indirectly from fires, the necessity for care in the handling of matches, burning tobacco, or any other form of fire in the open, and the consequences to the originator of a fire.

EDUCATION

In an educational campaign for fire prevention there must be built up among the people a different point of view from that now prevalent. For lasting results this is likely to come gradually, in some places only with the replacement of the old generation by the new. There are, however, many localities where already the educational work that has been carried on for 5 to 25 years has shown results in increasing carefulness with fire.

Education of children in the schools is considered one of the most effective means of accomplishing prevention. It would be desirable from the fire prevention standpoint to have instruction given on forest fires in all schools. To be effective, such work needs to be repeated

year after year so that finally children acquire the habit of carefulness with fire. It is probable that only in rural communities, where contact with the forest is closer than in urban centers, can intensive education of this type be introduced into already overloaded curriculums.

Observation of special occasions such as fire prevention week offer opportunity for some instruction on the subject.

Educational efforts in fire prevention employ, among the more effective media, motion pictures, posters and signs (Tenant 1941), lectures in person or broadcasted by radio, items in newspapers, published literature for people of all ages, special letters to selected mailing lists, and exhibits and gadgets such as fag bags (Larson 1942). The means used must be suited to the local conditions—natural, economic, and social—and consequently what may prove suitable in one place is less useful in another. Turney (1942) suggests that posters contain information as to how fires may be prevented rather than just urging prevention.

The signing of "brush-burner" pledges proved helpful in reducing number of fires in one case cited by Mullin (1942).

Personal contact with people living in or passing through the forested areas is a most effective method of education, but this is relatively so expensive as to be impracticable in dealing with all such people. Wherever it is not too expensive, personal contact should be employed. Coulter (1948) gives many pertinent suggestions with respect to making contacts and establishing good will, the first step in getting public cooperation in forest fire prevention. The method is particularly suited to forests with a low resident population and where outside visitors do not enter in large numbers during the fire season. If the resident population within or adjacent to the forest area is small, it may be advisable to see every family or at least the most influential members of the community. Contacts of this type should not be made once and abandoned but need to be repeated at least every year and preferably oftener. Frequent publicity is needed, especially during seasons of high fire danger, since warnings against carelessness with fire seem to make temporary rather than permanent impressions.

Where educational effort is conducted on a personal contact basis excellent opportunity is afforded to learn the true viewpoint of the person interviewed and the underlying reasons for his attitude. Education to fit the individual exactly can then be undertaken. Where a larger-scale educational program is conducted it becomes more difficult to make the information conveyed fit the people to whom it is given. Special skill is also needed in correcting wrong ideas even after they are

discovered. The importance of speeding up the educational campaign by accurately interpreting other people's viewpoints and recognizing the underlying causes and then correcting wrong viewpoints in regard to fire is so great as to call for the best scientific advice obtainable. For this purpose trained psychologists should prove helpful.

The Canadian Forestry Association for many years sent lectures and exhibits about Canada to carry the message of forest fire prevention to the back-country people of the provinces. Automobiles equipped with electric generators and motion picture projectors were used as well as a lecture and exhibit car run over some of the railroads. Itineraries were planned so that the lecturer seldom traveled more than 25 miles a day, but in a season of 5 months he aggregated distances of 50,000 to 60,000 miles and reached thousands of people each year. This program, continued for several years, undoubtedly helped in reducing the number of fires.

In 1928 a similar fire prevention campaign known as the Southern Forestry Education Project was sponsored by the American Forestry Association. Although this lasted for only 3 years it did much to arouse interest in fire prevention in a region where the annual burning of the forest is traditional.

Patrolmen, covering daily a definite territory, by their mere presence and by their contacts with the forest users assist in educating the public. In thickly settled but forested regions such patrolmen may be employed primarily for their educational value and effect on law enforcement, although they are also useful in detecting and suppressing fires.

A fire prevention project using general educational work and patrolmen proved very successful in Cape Cod, Massachusetts (Reynolds 1941). Two patrolmen were employed about 7 months a year during a 3-year period to cover an area of about 157,000 acres approximately 70 per cent wooded. Among other duties, the patrolmen interviewed 32,440 people. One result of the experiment was that the expenditure for educational work, patrolmen, and suppression was 20 per cent less than the amount spent for suppression alone in the 3 years preceding the experiment. Furthermore, the reduction in loss as expressed in area burned over was 80 per cent lower than in the 3 years preceding the experiment.

LAW ENFORCEMENT

The enforcement of laws dealing with forest fires can be of tremendous assistance in fire prevention. Sometimes enactment of new laws may be found advisable. On the whole most states already have

enough laws relating to forest fires. The main trouble is a lack of enforcement of the existing ones. One phase of the educational campaign should be directed toward those who are in control of the machinery for law enforcement. Until the prosecuting attorneys have been educated to prosecute fire cases actively and the judges have been brought into sympathy with the effort to control fires, law enforcement will lag.

After adequate law enforcement is initiated the campaign to secure full educational benefit from enforcement should be pushed. Wide publicity should be given to instances of prosecution and conviction for violation of the fire laws and to the enactment of new laws. News of this character will have not only a deterrent effect upon others in regard to carelessness with fire but also a general educational value in keeping the fire problem before the public.

If law enforcement is to be successfully used as a means of preventing fires there must be painstaking work to prove infractions of the fire laws. As a first step, forest officers should be familiar with their local fire laws and should know the rules of evidence and the details incident to successful prosecution of violators.

Compiling evidence may involve tracking, finding footprints and making casts of them, finding and photographing fingerprints, and searching for other clues (Talbott 1946). In connection with man-caused fires, particularly incendiary fires, discovery of the man who set it is often of equal importance with the immediate suppression of the fire. It may be of vital importance to look for clues while the fire is still small and before the clues have been destroyed by the firefighters. Suggestions for finding clues and gathering evidence are well described by Sipe (1946), who has had a lot of experience in convicting incendiaries. He stresses the fact that in almost every case some clues can be obtained. These may be in the nature of toolmark clues or prints of tires, shoes, or fingers as well as the more customary use of empty gun shells or detecting the people who are in the woods. Sipe does not think that a man has to be an F.B.I. agent, but he must be gifted with good common sense to know what clues to look for and how to protect and preserve evidence as well as to interpret what he sees.

As yet there are not large enough forces of men in the forest to detect and prosecute all infractions of the fire laws. Undoubtedly prevention would be strengthened by having a special force of men for the purpose of discovering and apprehending forest law breakers. It should pay in the long run to maintain in certain forest regions a force of men in the fire season primarily for law enforcement until people learn that

carelessness with fire is expensive for them. Allen (1925) proposed this idea years ago at a time when prevention was given relatively little consideration, and it has been advocated by Cowan and others (1937, p. 167) and is applied by the U. S. Forest Service in some places.

CLOSURES AND RESTRICTIVE REGULATIONS

Another measure, partly educational and partly direct preventive action, that should be employed is the use of either closures against entering forest areas or restrictive regulations of various types for entering and using forest areas. Closures, by which is meant the closing of a forest area to entrance by visitors, have distinct educational value through the publicity resulting from their announcement and enforcement. Restrictive regulations make the forest users fire conscious and have a deterrent influence upon carelessness with fire in the forest.

Absolute closure of a forest area to entrance by visitors may be used in periods of unusual danger. While enforced, it prevents man-caused fires. If complete closure is deemed unnecessary or impracticable registration of people entering the forest will serve as a preventive measure. The degree of fire danger should determine when such an extreme measure as closure of a forest area should be adopted in preference to the registration of visitors or to no restrictions other than the usual regulations being placed on people entering the forest. Short closures of forest areas during periods of high fire danger in the hunting season have become a common fire prevention practice in many states.

Restrictive regulations may include such items as:

- Registration of visitors.
- Checking visitors in and out of restricted areas.
- Prohibition of smoking or its restriction to designated areas.
- Requirement to carry axe, shovel, and water container.
- Temporary shutdown of logging operations.
- Requirement of permits for various activities such as:
  - Building camp fires.
  - Burning debris.
  - Starting fire in the open.
  - Sale, discharge, or possession of firearms.
  - Operation of various types of engines, such as coal- and wood-burning.
  - Burning in connection with charcoal kilns, sawmills, etc.

Restrictions on smoking should be issued, posted in suitable locations, and strictly enforced during the fire season. The customary restrictions on smoking prohibit smoking in the forest except at designated places. Usually, on national forest lands, smoking if permitted at all is allowed: (1) while the smoker is traveling on roads, provided matches and tobacco are entirely extinguished before being discarded; (2) in camps and at places of human habitation; (3) at any other place free from inflammable material, provided the smoker absolutely stops traveling while smoking and entirely extinguishes his tobacco before resuming travel.

Permits to build camp fires should be required where visitors are allowed to camp in the forest. Sometimes the right to build camp fires is included under a general permit allowing the privilege of entering and camping in the forest. Another excellent regulation is to require all parties intending to enter the forest to be equipped with ax, shovel, and water container.

Permits for burning brush when clearing land or for starting any fire in the open during the fire seasons should be universally required as a preventive and educational measure.

In addition to carrying on a general campaign of education and law enforcement to secure fire prevention, effective work can be done, after a study of the local fire causes has been completed, by specializing in each locality on preventing the type of fire there prevalent. For example, in an area frequented by campers, efforts should be directed toward preventing the start of fires from this source. Fire prevention in the final analysis thus becomes an intensive local problem. The foundation of general education and law enforcement is essential, but it will be the skillful application of fire prevention principles to fit local conditions that will spell success.

A starting point in studying local fire causes is to make risk or fire-cause maps showing the location of individual fires attributed to each cause. With the aid of such maps, zones of risk occurrence often can be located that will prove helpful in planning preventive action. Past records showing the dates of occurrence for fires attributable to the various causes indicate the probable seasonal occurrence of each fire cause.

PREVENTION OF EACH STANDARD CAUSE

Each of the seven major preventable fire causes needs special consideration to determine how it may best be eliminated as a source of fires.

Railroads

Railroad fires may largely be prevented through:

1. Elimination of fuels that cast sparks.
2. Use of spark-arresting devices on locomotives.
3. Maintenance of the right-of-way in noninflammable condition.

Included under railroad fires are not only fires set by sparks and cinders escaping from the engines and cars, but also those originating from the carelessness of employees and passengers either on trains or on the right-of-way. Discarded burning waste, red-hot metal cast off from brake shoes, and improperly executed right-of-way burning may also set railroad fires. In fact, even fires set by trespassers (usually tramps) on the right-of-way are classed as railroad fires. Under these circumstances it should be evident that all railroad fires cannot be prevented by the use of one only of the methods of elimination suggested. At least the last method combined with one of the first two will be necessary. Each of the three merits consideration.

Elimination of Fuels That Cast Sparks. Coal and wood have in the past been the fuels commonly employed. Wood is now rarely used. Both of these fuels produce abundant sparks. Oil is practically a sparkless fuel * and gasoline even more so. Electricity as a source of power represents the ideal from the fire prevention standpoint. In considering a change from the dangerous fuels (wood and coal) to the use of oil, gasoline, or electricity the economic factor becomes important. The relative availability, suitability, and cost of these different sources of power usually will be a determining factor. In many instances it will be unwise and impractical to attempt the prevention of railroad fires through elimination of fuels which cast sparks.

A change to electricity or oil means at the best only that fires originating from sparks and cinders cast from the engine are prevented. Other classes of railroad fires still may start.

Use of Spark-Arresting Devices on Locomotives. A large share of railroad fires originate from sparks ejected from locomotive stacks. A railroad locomotive is a power plant of great capacity confined within

* Fires are started by oil-burning locomotives. Burning oil may escape from beneath the firebox and drip onto the track, and burning soot sometimes emerges from the stack. The practice of sanding the flues often results in casting out burning material from the stack. Spark arresters may be required on oil-burning locomotives.

relatively small quarters. In order to develop the required energy the fires must be burned under forced draft of high intensity. This results in carrying forward a portion of the burning fuel from the firebox to the front end of the locomotive and thence out the smokestack.

Unless preventive measures were taken, the progress of a coal-burning locomotive would be accompanied by a continuous ejection of hot fragments of fuel. This can be controlled by maintaining spark arresters in the smokebox or smokestack of the locomotive. Although hundreds of different spark arresters have been devised, employing various principles, most of them rely for their success upon one or both of two devices. Either metal screens or perforated metal plates with holes of such a small size that dangerous sparks cannot escape are provided or else the sparks and gases are forced by means of obstructions to follow an abruptly winding path in their passage through the smokebox and out the smokestack. The latter device results in the sparks becoming so beaten into small pieces as to be harmless when ejected.

Any reduction in the open area in the smokebox or smokestack caused by spark arresters tends to reduce the draft; on the other hand, any large opening may allow fire-bearing sparks to escape. A compromise must be arranged between these opposing factors in order to maintain the necessary strong draft and at the same time keep the ejected sparks below a given maximum size. In general, if the escape of dangerous sparks is to be prevented, the openings must not be larger than $\frac{1}{4}$ inch square, or (where perforated metal plates are used) $\frac{1}{4}$ inch by $1\frac{1}{2}$ inches in size. Sparks $\frac{1}{4}$ inch or less in size lose their heat quickly and when they reach the ground have temperatures too low to start a fire.

Wallace (1923) advises Draftac netting for screens with openings $\frac{3}{16}$ inch by $\frac{3}{4}$ inch and with strands of wire 0.135 inch in diameter. This netting prevents the passage of sparks larger than $\frac{3}{16}$ inch in diameter, furnishes good draft area, and possesses strength and durability.

Spark arresters are effective in preventing the escape of dangerous sparks, and consequently the start of forest fires, only when they are maintained in perfect condition. Owing to the hard wear to which they are subjected and to the likelihood of their warping under the heat, spark arresters easily become defective. The best practice requires a careful inspection at least once each week. In dangerous seasons daily inspection may be required.

Even when in perfect condition, spark arresters can prevent only those railroad fires which originate from locomotive sparks. Live coals frequently fall out of the ashpans and may roll off the track and set fire on the right-of-way. For this reason it is necessary that all ashpan doors be tight fitting and stay closed while the engine is moving and that there be no openings or holes in the ashpan unprotected by screens from which coals might drop.

Smoking-car windows should be screened to prevent passengers throwing out lighted matches or burning tobacco.

Maintenance of the Right-of-Way in Noninflammable Condition. Even if one or the other of the two suggested measures for preventing railroad fires is employed, the causes of railroad fires from other than locomotive sparks and live coals may still start forest fires. Most of such fires originate on or close to the track. Their number can be reduced, provided the right-of-way for 50 to 100 feet on each side of the track is kept free of inflammable material. Methods of clearing and maintaining in proper condition a clean right-of-way will be discussed later under "Firebreaks," Chapter 8.

A properly cleared right-of-way assists also in preventing fire starting from live sparks cast by locomotives with defective spark arresters. The investigations of Goss (1907) and Wallace (1923) indicate that practically all sparks of fire-bearing size fall to the ground within a zone not more than 100 feet in width bordering the track. Fire-bearing sparks falling on a properly maintained right-of-way are not likely to set a forest fire.

Clearing railroad rights-of-way illustrates the fact that reduction of inflammable fuel can be carried to the point where it actually serves as a preventive measure to the start of forest fires. It is practicable in many parts of the country either by burning over or by cultivation to keep railroad rights-of-way in such a noninflammable condition that fires cannot start on them.

Camp Fires

Education and law enforcement are effective means of reducing this class of fire. In addition, special measures may be employed, such as requiring permits to build camp fires or to enter forest areas, registration on entering the forest, closure of forest areas during dangerous seasons, suspension of the hunting season, and required use of prepared camp sites. Since most of the people responsible for camp fires enter the forested region on traveled routes, either roads, trails, or streams,

they can frequently be reached through personal contact. The known presence in the territory of a patrolman or forest ranger does much to prevent campers' fires. Camp grounds should be kept so free of inflammable materials that fires cannot start.

Smoker

Fires from this cause are more difficult to prevent than those set by campers because all classes of people may be responsible for smoker fires whereas camp fires originate only with the relatively restricted class of people who camp in the forest. Smoking may be prohibited in the woods during the fire season. Such a regulation if enforcible would eliminate smoker fires except those originating beside the highways that pass through the forest. A still more severe restriction would be to close the forest areas entirely and keep all people but members of the forest organization out of the forest during critical periods.

In forests where visitors must register on entering, the required signing of a clause under which the visitor agrees to pay the cost of extinguishing any fire set by him and to pay for any damage done would have an excellent educational effect. The discarding of burning matches and tobacco can also be prohibited particularly from moving vehicles and in areas of inflammable fuel.

Fires set by smokers have proved to be one of the most difficult classes to prevent. Indeed only through educational efforts and law enforcement constantly continued over many years can satisfactory results in prevention of smoker fires be hoped for. They are likely always to remain one of the chief causes of fires.

Debris Burning

The most effective measure for preventing debris-burning fires is the permit system, now quite generally used. Under this method, permits for burning brush must be secured from designated officials, preferably fire wardens acting under the direction of the state forestry department. This has the effect of making the brush burner careful not to allow his brush fire to get out of control. To be most effective the permits should allow burning to be done only during certain hours of the day (not later than 10 A.M. or not before 4 P.M.), should specify the period the permit is valid (the fire season excluded), and should be revokable whenever conditions become dangerous. Enforcement of the law against those who burn brush without a permit is needed in order

to make the plan a success. Virginia has found airplane patrol to be effective as a preventive measure against debris burners (Garth 1947). Messages are dropped from the plane beside men found burning brush in violation of the law. The knowledge that they could be watched from the air undoubtedly reacts to make brush burners more careful.

Incendiary

Educational efforts directed to showing specifically why fires are harmful to the interests of each individual incendiary should cause a reduction of fires, particularly when the incendiarism is not of the malicious type. Education by means of personal interviews, either with the people setting the fires or with friends who may influence them, should prove worth while. So far as possible remove the incentives which lead individuals to set fires. For example, where incendiary fires are set to obtain employment, arrange to have regular crews handle all the firefighting and do not hire other men for the purpose. The controlled use of fire under expert supervision for specific purposes may accomplish the results wanted by men now setting incendiary fires and avoid the serious incendiary fires.

The problem of incendiary fires set by people who believe they benefit from fires will never be satisfactorily resolved until communities reach substantial agreement as to the best use of the land. Frequently it is a question of the livestock industry versus forest crop production. An illustration of this is the situation throughout the coast region of northern California and Oregon, where the ranchers start incendiary fires to kill brush, reproduction, and second growth timber for the purpose of improving the grazing. The land is exceedingly productive for growing redwood and other conifers, but can be turned into grazing land of not too high quality. At present, grazing seems to the natives better paying; but, for long-time economy, timber undoubtedly is more profitable. A decision as to which tracts of land to put into pasture lands and which to keep in timber for best community interest must be made and accepted by the local people before substantial reduction of incendiary fires becomes possible.

The definite allocation of land units to use either for livestock production or for forest production with controlled use of fire on the former areas and exclusion of fire on the latter areas should reduce incendiarism (Ferguson 1937).

Against men actuated by malice rather than by belief that fire benefits them directly it is necessary to resort to law enforcement.

Law enforcement with convictions of guilty parties is essential to reduce substantially the number of incendiary fires in most parts of the country. Securing convictions is a difficult task as most evidence is circumstantial. The sentiment of the community must be against setting of fires before conviction for incendiarism becomes easy.

A good account of building up the prosecution against three incendiary fire setters, showing the difficulty of actually obtaining convictions, is given by Huber (1947).

Lumbering

The lumbering fires which start from engines either stationary or moving can be prevented by measures similar to those suggested for railroad fires.

The other fires which are likely to originate, in the areas being logged, from the carelessness of employees may be reduced in number through educational effort and through enforcement both of state laws and special regulations adopted by the organization concerned.

A preventive measure sometimes employed in localities of great fire hazard is to shut down the logging operation during the most dangerous portion of the day or season (Joy et al. 1942). In the Douglas-fir region of western Oregon and Washington strong support has been given this policy by the action of the insurance companies insuring felled timber and logging equipment in establishing a "humidity warrant" which requires the suspension of logging operations when the relative humidity is below 30 per cent.

A further advance toward the prevention of lumbering fires has been taken by the State of Oregon. This state now enforces a logging operator's permit law which makes it necessary to have a permit for carrying on any woods operation west of the Cascades during the fire season (Ferguson 1936, pp. 20–22). Under this law the state forester can suspend permits to operate during periods of high fire danger. Operators must meet certain requirements designed to prevent the start of forest fires. The State of Washington has a somewhat similar law.

Miscellaneous

Fires from miscellaneous sources are in general due to human carelessness. They can best be reduced by education and law enforcement. Although forest fires due to spontaneous combustion are usually considered unpreventable, yet something might be done toward prevent-

ing the development of conditions likely to result in fires of this origin. For example, forest fires have been reported as started by heat concentrated on inflammable fuels through the medium of pieces of broken glass bottles left in the woods.

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CHAPTER 7

Presuppression Activities in Fire Control: Detection

WHAT PRESUPPRESSION INCLUDES

It must be anticipated that, no matter how carefully conceived and well executed are the plans for prevention, still man-caused fires will start. In addition there are the fires from natural causes, principally lightning, which cannot be prevented. Preparations must be made to control all these fires. Consideration of the lines of work included under such preparations is the purpose of this chapter. The term presuppression activities is appropriate since the stage of preparedness must be attained before the necessity for fire suppression arises.

Just as in cities so also in the forest, the results are likely to be disastrous if, prior to the origin of the fires, inadequate thought has been given to the subject and insufficient preparations made for fighting fires. Quick, competent action is the key to efficient fire suppression. This can be attained only as a result of systematic preparations made before the fire breaks out. Experience shows that it is cheaper to pay for systematic preparedness than to meet the tremendous fire losses and suppression costs which otherwise result.

Presuppression activities must cover all phases of the fire suppression problem. They are here classified and discussed under the following headings:

Detection of fires.
Communication system.
Transportation system.
Firebreaks.
Equipment.

Personnel.
Fuel reduction and fuel mapping.
Fire-danger rating.
Fire-control policy and objectives.

Although for the purpose of this discussion each of these subjects is treated separately yet all are interrelated in practical application so that what is done along one line often is contingent upon the action taken in other phases of presuppression.

Before presuppression activities can be planned intelligently it is advisable that the facts in reference to risks, fuels, and other elements of fire danger be known. In the past and even today on many tracts information on such matters as fire causes, fire occurrence, and amount and kind of fuel is vague and generalized rather than secured from careful records of fire history and accurate surveys of present conditions.

Definite information as to fire causes, fire occurrence, and fuel type leads ultimately to a careful appraisal of the fire danger and a rating of the relative fire danger in the various portions of the territory which assists in planning presuppression activities to fit local requirements. Where fire control has not been carried on systematically for a long enough period to acquire this information, then presuppression activities have to be organized without an adequate basis and may require change as time passes.

DETECTION OF FIRES

If the area burned over is to be kept small by prompt suppression action, it is essential that forest fires be discovered soon after they originate. Detection of fires should not be left to chance, with the possibility that a fire may burn several hours before being discovered. In many cases detection within 15 minutes after the start of the fire is necessary for effective fire control (Show and Kotok 1937, p. 2).

The need of systematic arrangements for detecting fires on all areas under organized fire protection is universally recognized. In most large organizations the detection of fires has become a specialized function handled by men whose primary duty it is to discover, locate, and report promptly all forest fires. This does not mean that fires may not be discovered and reported by other people, but in the main the men charged with this special duty do detect and report a large percentage of the fires originating in a territory so protected. In settled sections

of the country, and particularly where the houses are located on the higher ground rather than in deep valleys, many forest fires are discovered by the local inhabitants. If these people are themselves forest landowners their own interest is a stimulating factor in obtaining prompt detection and report of forest fires.

When the forest area occurs in small blocks interspersed by numerous habitations it is possible that the local inhabitants will see and report all fires soon after they start and thus obviate the necessity for special forest fire detectors. The situation would then be analogous to that in towns and cities where voluntary detection and report is relied upon. On only a small proportion of the forest area can adequate protection be secured in this way.

In regions where the local population is in sympathy with the fire control program the people may be very helpful in reporting fires, whereas when the reverse is true the population may be harmful by setting rather than reporting fires.

The Lookout System

The system known as the "lookout system," now extensively employed in practically all forest regions for the detection of fires, consists in the selection of observation or lookout points distributed over the area to be protected. An observer or "tower man" is stationed during all or part of the fire season at each lookout point. The lookout system can be advantageously employed in all types of country. It is used in level sections and in mountainous regions. Much of the information in this chapter concerning lookouts is taken from "The Lookout System" by Osborne, Cowan, and Hersey (1947) where the subject is covered in more detail than can be afforded in this book.

Primary lookout stations are those at which an observer is kept permanently throughout the fire season for the purpose of detecting, locating, and reporting fires. Secondary stations are points, supplementing the primary stations, occupied occasionally for short periods in the most critical times. Observers on secondary stations will frequently function as firemen as well as detectors and will have the additional duty of going to the fires discovered in their territory.

When the system is properly developed, a network of lookout points is established with the stations so located as to cover directly as much as possible of the whole area. In theory every portion of the area should be in view from at least one station and preferably from two or three. Over flat regions the lookout points may be quite uniformly

distributed and practically complete coverage obtained. In mountainous country this is impossible without incurring undue expense. It was found in the northern Rocky Mountain region (Hornby 1936, p. 79) that to see 100 per cent of the area would require 500 stations per million acres or an average coverage of 2000 acres per station and would involve a great deal of overlapping of the seen areas. To secure 65 to 80 per cent coverage in that region would require only 50 detectors per million acres having an average coverage of 20,000 acres apiece.

Points must be carefully selected in mountainous regions on the basis of the character and extent of the view from each station, appraised in relation with those from adjoining points, and considered in reference to the portions of the area which need to be most closely watched because of frequent fire occurrence or dangerous accumulations of fuel. Seen-area maps may be prepared, based upon either field sketching, the profiling method, or the relief model method (Show et al. 1937, pp. 5–9, 18), showing the areas seen directly from given stations, to assist in deciding upon the locations for a network of lookout points. It is important that the lookout network be arranged so that no large unseen areas exist unless they be in places where fire danger is low.

The number of stations needed to cover a given region depends upon atmospheric conditions, which may assist or hinder visibility, upon the fire risk, upon the topography and the complexity of the land surface either presenting or favoring views of large areas surrounding the lookout points, and upon the relative height of the lookout points with reference to surrounding country.

Experience in fire detection shows that satisfactory discovery of fires cannot be counted upon for distances greater than 15 miles and then only under favorable conditions of visibility. In most parts of the country a 6- to 10-mile coverage around a primary lookout station is a better maximum.

In planning the location of lookout stations Brown (1935) and Show et al. (1937) indicate that the risk factor (frequency of fire occurrence) is the primary one upon which to judge the relative desirability between proposed lookout points. In applying this criterion, seen-area maps are prepared for each lookout point and used in conjunction with maps of past fire occurrence to establish a figure of expectancy as to the number of fires likely to be seen from each proposed lookout point. The point with the highest expectancy rating is the first selection in a given region. Then starting from the first point an expanding network of stations is picked to give reasonably complete coverage

with the least number of stations. This method is practicable only after the years of past fire history have been recorded and fire occurrence is known in detail. In first organizing protection the use of seen-area maps (which are quickly made) must be relied upon chiefly, together with general knowledge of the principal risk and hazard areas.

In Region 2 of the U. S. Forest Service where the need for a complete lookout network of primary stations is not so clearly defined as in some other parts of the country, Brown and Lobdell (1938) advised using fuel-type maps, fire-occurrence maps, and fire-danger maps in combination to obtain ratings of the possible locations for establishing the primary lookout stations needed.

The efficiency of a lookout observer in discovering fires on the area directly seen from the station changes with visibility conditions. When the air becomes loaded with dust particles or smoke from burning fires closes in, the visibility distance from the lookout station is shortened. Since primary lookout stations are likely to be located on the basis of good visibility conditions it becomes necessary to reinforce the primary network with secondary lookout stations which can be occupied when the atmosphere is hazy and therefore poor visibility prevails. Effective location of these secondary stations requires a knowledge of the distances, under specified conditions of visibility, at which small columns of smoke such as are made when forest fires start can be seen.

McArdle (1936) in studying visibility factors in the Pacific Northwest found a range of 3½ to 15 miles as the distance at which small smokes could be seen depending on amount of haze in the atmosphere. He advised a primary lookout station network based on a 15-mile radius of visibility and a secondary system of stations with an 8-mile radius of visibility inside the primary system. A fact brought out in this study is that a person can see smoke farthest when looking into a low sun and against dark-colored backgrounds. Bruce (1944) investigated smoke visibility in California and claims that previous studies of visibility distance have failed to stress sufficiently the variation due to the background. He distinguishes between light, dark, and mottled backgrounds. Where mottled or light-colored backgrounds are common, lookout stations will have to be much closer together than where a uniform dark color forms the background. He also shows the importance to visibility distance of the angle from the observer's eye to the smoke and to the sun. A small angle, with the sun practically back of the smoke, gives longer visibility distances than when the sun is back of the observer. He considers backgrounds important in locating lookout stations. In checking performance of lookout personnel

this subject must be given consideration, as the correct visibility distance to which a smoke can be seen depends upon background and sun angles.

Jemison (1940) reports the average visibility during fire weather for eastern national forests to range from 5 to 11 miles. Smoke from homes and factories accounts for the larger part of the atmospheric haze. He bases his measurement of visibility on smokes of ⅛-acre size, rather than on the "standard" test smoke bomb or smoke candle (designed to simulate the smoke from a small fire 12 by 12 feet) listed in the *Fire-Control Equipment Handbook,* since with the light fast-fire-spreading fuels in the East the average fire reaches this size within the 15 minutes allowed for detection time.

Morris (1947) summarizes the principles governing smoke visibility and emphasizes the importance of understanding the factors which affect it particularly where expensive aerial patrol is employed for detection. In this case the course flown may be so arranged as to render smoke in certain places more easily seen.

In order to know when secondary lookout stations should be occupied, continuous knowledge of current visibility conditions is required during the fire season. This information can best be secured by taking readings with a visibility or haze meter especially designed for the purpose (Byram and Jemison 1948). As defined in the *Fire-Control Equipment Handbook* the haze meter "measures the optical density of the atmosphere and expresses the measurement in distance at which a 'standard' smoke can be seen. The 'standard' smoke is the amount that would emanate on a hot, midsummer afternoon from a fire 10 by 20 feet in Douglas-fir or ponderosa pine duff in Oregon or Washington or a fire 12 by 12 feet in hardwood leaf litter under dry conditions in the East" (Anonymous 1946, pp. A-11 to A-12).

For western Montana and northern Idaho, Hornby (1936, p. 60) advised that a 6-, 8-, or 15-mile radius of vision distance be secured by manning the appropriate lookout stations depending upon whether the burning conditions are of maximum, average, or minimum severity. With a 6-mile radius of vision an observer covers approximately 70,000 acres.

Most of the eastern as well as the western states have good lookout systems.

Massachusetts maintains 50 well-equipped lookout towers, covering the entire state. Since the land area is more than 5,000,000 acres the average area covered by a lookout station is approximately 100,000

acres of wooded, urban, and open areas. This means that the average maximum radius of territory covered by a single station is about 7 miles. Very little if any of the wooded area of the state is farther than 10 miles from a primary lookout station.

There are 137 forest fire observation stations in Pennsylvania concentrated in approximately two-thirds of the state. Each station must overlook on the average about 135,000 acres.

Equipment of Lookout Stations. When the lookout system was first used, little effort was made to improve the natural conditions on the lookout point. A bare summit or a tall tree climbed by a rude ladder of spikes was the extent of the facilities available for the observer. Today this is considered inadequate for the primary lookout station where an observer remains throughout the fire season. The observer, to function with highest efficiency, must be housed close by his work, be provided with protection against the elements while on the lookout point, and be given special equipment for accurately locating and reporting fires.

The finest type of lookout station consists of a small one-room building with unobstructed view through windows on all four sides. The building may be located on the ground if a bare peak is utilized as the observation point. Usually enough such sites cannot be found, and timbered hills, flat country, or relatively low bare hills must be used. The lookout room should then be elevated above the ground to a height sufficient to command the required view. For this purpose a steel windmill tower with a specially designed glassed-in room at the top is commonly employed. Frequently towers 100 or more feet high are needed.

The observer should if possible live in the lookout room. It is less advantageous to have him quartered near by in a less windy location. Where the stations are on high mountains the necessary water supply for the observer frequently presents a problem.

A telephone line or some other reliable method of communication connecting the lookout station with the firefighting organization is essential for reporting fires. The observer must not only detect the fires promptly as they start but also report accurately the location of the fire. Special equipment for locating fires should be provided in the lookout room. The best available map of the country surrounding the lookout station should be provided and permanently mounted, properly oriented, on a table in the center of the lookout room. A topographic map is preferable since it may assist in locating the fire on

the map. In order to assist in determining the direction and distance to the fire an alidade or similar equipment is required. The best-equipped stations are provided with an instrument known as the Osborne fire finder (Osborne, Cowan, and Hersey 1947) which enables the observer to read with precision both horizontal and vertical angles to the fire and, if a good map is available, to determine immediately the location and size of the fire. Vertical angle readings are of most value in locating a fire in regions where definite landmarks are lacking, the timber canopy is continuous, and cross readings from other lookout stations cannot be obtained. Less expensive instruments than the Osborne fire finder are available, some of which are listed in the *Fire-Control Equipment Handbook* (Anonymous 1946, pp. B-1 to B-5).

In general an observer thoroughly familiar with the country can locate many fires simply by ocular means without the use of instruments. Where more than one lookout station covers a particular territory the compass direction may be reported from each station and these lines plotted on a map. The intersection of the lines gives the location of the fire. A well-trained observer if equipped with a good map and an Osborne fire finder should report the locations of the fires accurately within a relatively few feet. The accuracy of location should be better when two or three stations participate in fixing the point.

The observer on a lookout station is usually only one of a group of lookouts reporting to someone at headquarters as fires are discovered. The latter may be the ranger, fire warden, or other officers. Where business warrants it, as on a national forest dealing with many fires, a special man, the fire dispatcher, may be assigned to the job of receiving reports from lookouts, determining the exact location of the fires from one or more reports on each fire, and finally dispatching the required crew to suppress the fires.

The dispatcher in locating the fires may employ several methods. Osborne, Cowan, and Hersey (1947, pp. 56–70) describe five methods listed as follows:

1. By delineation of sight or plane table method. This can be employed on fires sighted from only one station. It is done by the lookout observer as he looks along his line of sight to the fire, who, by observing the topography in relation to the smoke, fixes the spot on the map.

2. By plotting the intersection of horizontal angles from two or more lookouts. This is done graphically in most cases, though it can be done more precisely trigonometrically.

3. By plotting the intersection of vertical angle with profile. Simply stated, the line of sight on the fire is projected at the determined vertical angle until it enters the ground on the plotted profile. This point is the location of the fire.

4. By location with the panoramic profile method. This is usable only with the older models of Osborne fire finders.

5. By the photo survey method. An important development for improving the technique of fire detection is the use of graduated photographs taken from each lookout station with a specially designed photo-recording transit (Anonymous, 1946, pp. E-1 to E-3). The fire dispatcher equipped with a set of pictures obtained with this camera, on receiving from a lookout observer notice of a fire reported by azimuth and vertical angle, gets out the right picture and is able to locate the fire accurately and obtain from the picture a great deal of information helpful in suppression of the fire.

A special fire dispatcher's desk has been developed in Region 1 of the U. S. Forest Service. The main features of the desk are a set of mounted aerial photographs and a stereoscope under which the pictures can be studied (Anonymous 1946, pp. C-2 to C-3). The pictures have section lines superimposed and give a fine relief picture of the topography. They are exceedingly useful, particularly in rough topography, for locating fires and indicating the type of country in which the fire is burning, as well as for other fire business.

Smoked glasses to reduce the amount of light entering the observer's eye will prove helpful. McArdle and Byram (1936) developed specifications for the type of sun glasses or goggles which would give the observers the best protection for their eyes and at the same time not decrease efficiency in seeing smoke.

Binoculars do not help appreciably in detecting the fire. After the fire is found they enable closer inspection of the spot and may assist the observer to separate real smoke from something that looks like it and to give more details of location in reporting. A new process developed during the war enables the efficiency of binoculars to be increased by coating the optical lenses and prisms with a metallic film of magnesium fluoride (Reichert 1946). The job has to be very skillfully done in order to be efficient. It should pay for itself many times over in the course of a season because of the general improvement and correctness of the observer's reports and reduction of false alarms. The coating gives increased transmission of light and reduction of glare as its two chief advantages.

A reliable alarm clock for insuring concentrated survey of specific areas at prescribed times is advised. The observer should have a stool with glass insulator legs to sit upon when phoning during lightning storms. A good mirror mounted on a telescoping tripod will be found useful in triangulating between lookout stations. A set of panoramic pictures with the topographic features named of the territory surrounding the station or aerial photographs are helpful to the observer particularly when new to the territory.

The observer should be on duty from daylight to dark on days when fires can burn. He may even have to look his territory over at intervals in the night during critical periods and possibly may need to be regularly on duty at night. Many fires start at night in some parts of the country and if not discovered until morning may gain dangerous size. Where this possibility exists, night observation is essential. When climatic conditions make fires impossible the observer may be detailed temporarily to other work near his station.

Service as a primary lookout observer is exacting work and requires first of all good eyesight and conscientious devotion to duty. Byram (1940) has suggested a method of testing the eyesight of lookout men. The best plan to secure constant vigilance on the part of the lookout is to require reading every 15 minutes or so selected visibility targets uniformly scattered around his range of vision. This routine inspection is standard practice at many lookout stations on western national forests.

Lookout stations located on accessible points are of assistance in the education campaign for fire prevention. Some of these stations are visited each year by hundreds of people who thereby gain new impressions of the forest fire problem.

Even after a fire has been accurately located on the map by the lookout or dispatcher it may not be easy for the firefighter to find the fire. In most parts of the country finding the fire is a simple matter once its exact location is reported. But in dense timber it may be impossible for the firefighter to see the fire even when he is close to it. This is particularly true of the slow-burning smoldering type of fires often characteristic of small fires in dense timber. The smokechaser sent out to such fires often needs compass, map, and protractor, with detailed information from the dispatcher as to the exact location of the fire. Methods of finding fires in the field are described in detail in the *Fire Control Handbook,* Region 6 (Anonymous 1945, pp. II-8-28 to II-8-36).

The Value of Patrol in Discovering Fires

The lookout system has replaced to a great extent ground patrol over designated routes for the detection of fires. It has not, however, entirely replaced patrol for this purpose. There are special situations where ground patrol is still effective in discovering fires which start thickly concentrated in well-defined zones. Instances of this sort may be found along railroad lines or traveled routes through forested areas, and on some logging operations.

In mountainous country where deep valleys and canyons occur the primary lookouts if placed on the relatively high peaks often cannot see the lower slopes and valley bottoms. Since travel is likely to follow the valleys and create a high fire-risk zone, patrol is frequently needed to cover these areas unseen by the lookouts.

Patrol should make use of all the vantage points along its route for the purpose of obtaining the widest views possible over the territory covered to discover fires which start back from the patrol route. When the lookout network is expanded in periods of high danger and poor visibility, the secondary lookout stations are manned by lookout firemen whose duty is to detect the fires in their immediate territory and go to fight them. These men may stay on a given secondary lookout position until a fire is discovered or they may cover a route over several lookout points with the maximum of a few minutes' travel time between points.

In regions where the topography is very complex and the valleys deeply cut as in parts of northern Idaho and western Montana many lookout points may be needed to cover the area adequately. Under such conditions the system of lookout firemen, combining the two functions of detection and suppression, is likely to prove more effective than fewer full-time lookout observers and a separate force of firefighters.

These lookout points do not need special equipment except that means of communication should be available to the patrolman for reporting the discovery of a fire or for receiving information in reference to some fire near his route which may have been detected by other methods. Usually telephones are not available for the purpose unless the patrol route happens to follow or cross existing telephone lines. The portable radio furnishes the most effective means of communication for the patrolmen.

Patrol would be an expensive method of discovering fires if the patrolmen were employed solely for this purpose. Fortunately ground

patrol has other, more important functions than solely the detection of fires and will be employed primarily to assist in education, law enforcement, and fire suppression even though not needed in detection.

Ground patrol may employ any mode of conveyance—canoe, motor boat, horse, motor cycle, automobile, or foot. The tendency is toward motorized patrol.

In some states (Idaho, Kentucky, Oregon, and West Virginia are examples) ground patrol is compulsory for forest landowners, although detection is not the main function of such patrol. Other states have laws making patrol along railroad lines compulsory under certain circumstances.

Aerial Patrol in Fire Detection

Aerial patrol was early tried in fire detection but until recently was considered less effective for this purpose than the lookout system. It was considered improbable that aerial patrol would ever replace the lookout system for discovering fires because of its high cost and lack of continuous view over the territory. Rarely if ever could it be justified for detection alone, on account of the cost; although in periods of high danger when smoke obscured the view from lookout stations special trips by aerial patrol to hidden areas, or specific tracts recently exposed to severe lightning storms, might be of value in detecting fires. Since the aerial patrol can fly directly above the smoke and haze and see down through it, fires hidden from the lookout observer may be detected. Greater use of aircraft for fire detection is now being advocated. The next few years are likely to see changes in the relative position of lookout stations and aerial patrol for detection purposes. Two opposing viewpoints are cited in the following paragraphs.

The comparative value for fire detection of ground patrol, aerial patrol, and the lookout system, for the Pacific Northwest at least, is discussed by Osborne, Cowan, and Hersey (1947, pp. 1–2). They believe the lookout system will remain the main reliance for detection because of its economy and success in early discovery of widely scattered fires. Ground patrol because it requires a high cost for the acreage protected is useful on high risk areas along railroads, highways, and on logging operations. Their opinion is that aerial patrol should be used only to supplement rather than to take the place of lookout stations.

Different conclusions were reached by Hand and Harris (1947) in a trial of aerial detection started on 2,000,000 acres of forest in Re-

gion 1, U. S. Forest Service. These authors believe that aerial detection has been retarded in its development by prejudices against the rather ineffective use in the past of air patrol. This study made a comparison between costs of detection by the lookout system and by planes which were flown on a schedule to give the same frequency of inspection as obtained by lookouts. The unit cost of the plane ranged from $20 to $40 per hour whereas the present cost of lookouts is about $16 per man-day for salary, subsistence, and prorated overhead. The results of the tests indicate that the ground system is cheaper up to a 52 per cent coverage; from that up to 73 per cent coverage costs are approximately the same; whereas, if more than 73 per cent coverage is to be secured, the planes will give cheaper service. The logical conclusion is that the most efficient system will be obtained by a combination of ground service and planes. Probably the planes will give better flexibility for covering critical situations with a greater intensity than could be obtained cheaply from the ground system. They will also save a good part of the large investment in servicing the stations which are required by a ground system. Bosworth (1944) earlier had called attention to the savings possible through elimination of improvements and lessened maintenance.

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CHAPTER 8

Presuppression: Communication, Transportation, and Firebreaks

COMMUNICATION SYSTEM

In all branches of fire control a reliable communication system is essential. Without rapid communication prompt discovery of fires is of no avail as the information cannot be passed on quickly to the fire-fighting organization. The lookout stations must be connected with the men who are responsible for fire suppression. They, in turn, must be able to communicate with other parts of the forest and be connected through the commercial lines with the outside world.

From the standpoint of fire protection alone, entirely aside from its other numerous and essential uses, a good communication system can be justified. As a matter of fact, a communication system is needed in practically all lines of forest activity and hence should not be viewed as an investment solely for fire control. Today the telephone is used as the principal vehicle of communication. In settled regions the regular commercial lines are often adequate; but in the more heavily wooded sections of the country, as yet not intensively developed for timber sales or other productive use of forest resources, existing lines must be supplemented by the construction of all or a portion of the line needed in forest protection and administration.

Telephone construction in the forest can be of a simple, relatively inexpensive character and can be installed and maintained by the forest organization (Allen and Simson, undated).

As the volume of forest business increases the tendency is toward a better-constructed telephone system, often changing on the lines hav-

ing greatest use from the grounded line to the metallic circuit (Brown and Funke 1936).

The radio is used as a means of communication in forest fire control, and its employment for this purpose is increasing. It is not expected to replace the telephone entirely but there are situations where radio gives a more flexible service and will prove less expensive than the telephone.

Where a close network of commercial telephone lines already exists, there will be little need of using the radio for ground communication, although even in some of the better-settled portions of the country the investment may be worth while. If communication between airplanes and ground stations is desired, the radio is likely to prove invaluable even in regions well covered by telephone lines. In inaccessible regions where travel is difficult and where even inexpensive forest telephone lines have not been constructed the radio may be the sole method of quick communication between the various members of the fire-control organization in the field and at headquarters.

Direct communication by radio between an airplane observer and the man on the ground in charge of the fire can improve the work of suppression on large fires, which are too big to be seen by the man on the ground at all points simultaneously.

The radio is especially valuable for firemen and others in the forest when not close to a telephone line. They can carry a portable set and from wherever they may be communicate directly with headquarters.

Probably the ideal method of communication for forest protection is to have a telephone network extending over the forest and to have this supplemented by radio for men working away from the telephone lines and for communication between air and ground.

The development of radio into a means of communication practical for forest use has been accomplished by the U. S. Forest Service which already has designed a variety of models adapted to the several needs of the fire control organization (Anonymous 1946).

However, not all the difficulties in obtaining satisfactory use of radio under forest conditions have as yet been overcome. Further improvements may be expected.

TRANSPORTATION SYSTEM

Once notified that a fire is burning, the firefighters try to arrive on the scene while the fire is still small and easily controlled. Adequate transportation facilities provided in advance must be available in

order to make such action possible. The question naturally arises as to what constitutes adequate transportation facilities. The answer involves a knowledge of the maximum time which the firefighters may spend in traveling from the starting point to the fire and yet arrive in ample time to keep the fire within the limits specified by the management objective as to allowable area burned over (see page 156). The time needed which can be allowed for travel will differ according to the fire danger prevailing in a given forest or fuel type. Suppose that in a given forest type this maximum time, often termed hour control, is fixed as ½ hour. Then, in theory, such transportation facilities should be provided as will enable all parts of the type area subject to fires to be reached within this time standard.

At this point it is desirable to discuss the subject of elapsed time of which the time allowed for travel is only one part.

In order to further the systematic preparedness so essential to successful fire-control performance, standards of elapsed time or the difference in time between the beginning of any action and its actual accomplishment are established in fire-control planning for the various phases of presuppression and suppression activities that can be influenced within definite narrow time limitations. The various divisions and limits of elapsed time standards recognized in fire-control practice are customarily subdivided as follows (*Forest Terminology* 1944):

1. Discovery time, which is the elapsed time from the start of a fire (known or estimated) until the time of first discovery which results directly in subsequent suppression action. In practice, the detection system is commonly devised with the objective of discovering fires within 15 minutes after the smoke is visible above the tree tops.

2. Report time, which is the elapsed time from the discovery of a fire as defined above until the first man who does effective work on the fire is notified of the existence and location of the fire. A minimum of 2 to 5 minutes is usually set up as the report time standard. This means that the communication system must be adequate to insure the reporting of fires to a dispatcher or central office within 3 minutes on the average after their discovery by a responsible detecting agency.

3. Get-away time, which is the elapsed time from the receipt of the report of a fire by the man taking initial suppression action and his departure for the fire. Get-away time standards are dependent upon the mode of travel so that they may range from 3 to 5 minutes in the case of foot or automobile travel up to 15 minutes when horses are used for transportation.

4. Travel time, which is the elapsed time of the first man to arrive at a fire from the time he starts for it until he arrives at the fire. Travel time standards are governed largely by the mode of travel in conjunction with the type of transportation system that is available plus the factor of safe rates of speed involved. Thus, they may be concerned with rates of travel as low as 2 miles per hour, in the case of foot travel across rugged country, to as high as 45 miles per hour with passenger automobile on paved highways and 100 miles per hour or more in those instances involving the use of aircraft.

5. Attack time, which is the elapsed time that begins when the man who performs the first effective work on a fire learns that there is a fire and ends when he begins first control work.

6. Control time, which is the elapsed time from first effective work until the fire is controlled or until the time the perimeter of the fire is no longer increasing.

7. Mop-up time, which is the elapsed time from the completion of control work until enough mop-up work has been done to insure that the fire will not break out.

8. Patrol time, which is the elapsed time from assurance that a fire will not break over (mop-up and cold-trailing or controlling a partly dead fire edge by careful inspection to detect any fire, digging out live spots, and trenching short sections of live edges completely) until no further patrols around the fire edge are needed.

9. Hour-control time, which is the estimated or probable time that will elapse between the origin of a fire at a given point or locality, and the arrival of the first man or men of a given suppression force, distributed according to the prearranged fire plan.

Returning now to transportation problems, we find that in practice it is sometimes impossible at reasonable expense to bring every point within the maximum allowed travel time. If an hour-control map of the forest is drawn, showing graphically the number of hours which it takes to reach each part of the forest, the portions inadequately developed with transportation facilities will be graphically depicted. Obviously the speed at which a fireman can travel will be the determining factor in the time required to reach specific points. His speed is fixed by the natural factors of topography and vegetative cover and by artificial aids at his command such as a road, trail, airplane, automobile, boat, or horse. Naturally, if good roads exist and automobiles are available, the distance from headquarters covered in the same time will be much greater than if the route must be followed on foot through rough or brushy country and up a steep slope.

With the time standards as a beginning point, a transportation system for putting men on the fire line suited to the local conditions can be planned. The system should include units of differing degree of refinement, comprising several classes of roads and graded and ungraded trails. Norcross and Grefe (1931) were the early leaders in planning transportation systems for the western forests. An example of the way in which the principles of Norcross and Grefe are applied in designing forest transportation plans to meet the needs of fire control in California has been described by Brown (1937*a*, 1937*b*).

Transportation is needed in fire control not only for delivering the firefighters to going fires but for moving and servicing other members of the fire-control organization.

The transportation system is vital for the use and administration of the forest as well as for its help in fire control (Morrell 1927). The character of the transportation facilities which are appropriate at any given stage in the economic development of a forest depends primarily upon these other uses rather than upon the fire problem. Jones (1942) emphasizes the point that forest transportation should be planned as a development to take care of all forest resources. Only where essential to meet hour-control requirements should a road be located and built solely as a fire-control project. In any case the location should be such that it fits into the ultimate road system required to serve all forest resources. The objective of "the transportation planner, once decision on land use is made, is concerned with determining a system of roads that will most economically serve all forest resources, satisfy protection and administration requirements, and at the same time fully meet public travel needs. This system must be provided at the lowest economical cost and it must be justified on the basis of returns in value from the various resources and users."

The older settled sections of the country where logging has passed over the forest one or more times already have the transportation network laid out on the ground and partly developed. In such regions when forest management is taken up it is ordinarily possible to make use of roads previously established and to put into a usable condition the roads and trails needed for fire control at relatively low cost, and sometimes in conjunction with a revenue-producing use.

The virgin forests which occur principally in rough inaccessible areas present a more expensive problem of transportation development. Here the area if protected from fire in advance of logging operations requires the building of an entire transportation network for fire control. Ultimately, of course, the system will prove useful for a variety

of revenue-producing uses. This contingency should be kept in mind so that the system may later serve as the nucleus for the permanent transportation system needed for all forest uses combined. In the beginning the transportation system in undeveloped regions might consist either of roads or of trails or, what is more logical, a properly balanced combination of the two types. If trails predominate, the firemen must be rather widely and uniformly scattered over the area, but if one or more automobile roads penetrate the forest these men may be concentrated at fewer points.

The trail system should be the forerunner of and supplemental to a road system expanded gradually as needed until ultimately the entire forest area has the road mileage requisite for timber and other uses. As an illustration of intensive management the Keene Forest of the Yale School of Forestry, located in southern New Hampshire, has a system of truck roads bringing all points in the forest within $\frac{1}{8}$ mile of these roads. None of these roads were built for fire-control purposes. They were developed to facilitate extraction of timber. Only in wilderness areas should roads be tabooed.

Hornby (1936, p. 68) advises locating firemen at stations where they can act as detectors and smokechasers and then building roads to these stations. He asserts that under this guiding principle the cost of roads and men will be much less in country like the northern Rocky Mountain region of the U. S. Forest Service where detection and attack is a combined function. The objection that the lookout point may be unoccupied while the detector attacks a fire is relatively unimportant because a large share of the area is seen from two or three stations.

In addition to the transportation facilities already mentioned (which in most forests comprise the larger part of the system), there are other means such as railroad lines, waterways, and aircraft. Lakes and streams may furnish the main arteries of travel in certain regions like the Lake states, northern Maine, and eastern Canada.

Aircraft have already proved their value as a means of transporting firefighters, equipment, and supplies. In undeveloped regions lacking roads aircraft can serve efficiently as the vehicle of transportation. Men and supplies can be delivered by aircraft either on landing strips or by parachutes. There will be periods when, because of smoke or fog, flying will be too hazardous and supplies cannot be delivered by air until conditions improve (Anonymous 1945, p. III-5-1).

Supervisory personnel needed to take charge of fires are often transported by air in emergencies to save time even though slower trans-

portation by road is available. However, the development of an adequate number of landing fields for fire control purposes in rough mountainous country often proves impractical, since putting men and supplies on fires located anywhere within the forest area may be required. Even before World War II the U. S. Forest Service had pioneered in this field and so well perfected the technique of dropping men, supplies, and equipment from airplanes to the ground (Wernstedt 1937) that airplanes could be used profitably for the purpose when landing fields were unavailable (Campbell 1939).

Parachuting of firefighters onto going fires was first used by the U. S. Forest Service in 1940 (Lindh 1941) following tests made the previous year. Lindh's conclusions are that trained men can be safely landed in rough timbered country at altitudes up to at least 8000 feet and in winds of 30 miles per hour velocity. The use of these firefighters is not considered economical where the road system has been completed but is worth while in inaccessible country.

Godwin (1941) estimates that there may be as much as 15,000,000 acres in the Rocky Mountains and westward which might economically be covered by smoke-jumpers.

The U. S. Forest Service has been experimenting with helicopters and believes that they can be improved so as to be of value in fire control (Funk and Knudsen 1947; Jefferson 1948). Principal points which need correction are in equipping them with such additional devices that they can hover close to the ground and get in and out of small openings. The chief use of helicopters in fire control will come in supplying fire camps, particularly those that are of the side-camp type and those which cannot be easily serviced by the conventional plane. It is probable that the helicopter can be developed in such a way that it saves time as compared to other aircraft and succeeds in carrying nearly as much equipment as the planes now used in fire-control work.

Where the country is dotted with numerous lakes hydroplanes can be used to advantage, as the lakes furnish all the necessary landing places. Hydroplanes are used commonly in fire control in northern Maine and eastern Canada.

The transportation system will fall short of its highest usefulness in fire suppression unless sufficient units of the vehicles of transportation most appropriate for the road, trail, or waterway system established on a given forest, or for the air, are arranged for in advance and are ready for instant use in transporting the firefighters to the scene of action. The importance of this action is stressed by Jeffer-

son (1947) in an article entitled "Fire Control Logistics." Logistics which employ details of transporting, equipping, and supplying fire-control operations has been neglected in the past. Not enough emphasis has been put on the subject. It is one thing to have provided a given number of pieces of equipment, but unless provision is made for breakage, and for getting the material out to the fire, this equipment is often not really available. The definition of fire-control logistics would be the art of delivering man power and materials already planned for in the right quantity, in the right places, at the right time. Transportation both on the ground and in the air and over water must be considered in fire-control work. More attention should be paid to training men in the techniques of logistics, a field which today is practically untouched.

Truck transportation is probably the principal means for taking firefighters to the fire. Where motor roads exist, every administrative subdivision of appropriate size should have a fast truck outfitted with all tools and equipment needed by a firefighting crew and designed to carry the crew as well as the tools to the fire.

In selecting trucks for fire-control purposes, load capacity and speed in transit are the two principal points to consider. The character and condition of the roads over which the truck will run must be considered. It is desirable to use as speedy a truck as the roads make practical. If the transportation system contains considerable mileage of trails traversable by tractors, though not by trucks, the tractors may be equipped with trailers to carry supplies. Trails suitable for tractor and trailer use can be constructed at a fraction of the cost spent in building roads suitable for fast trucks and may be the best type of ground transportation facility to develop inaccessible country, especially when the trail can be built by a bulldozer (Heustis 1938). Rice (1940) describes the development and use of a trail tractor and a trailmobile, or small automobile with 35-inch tread. This tractor can be used for trail construction and for hauling trailers. Either the trail tractor with trailer or the trailmobile can deliver supplies over trails at less cost than by pack stock. "A reasonably smooth trail grade is necessary, which presupposes annual blade maintenance."

Forest firefighters in all parts of the country have shown excellent initiative in developing specially equipped trucks to meet the conditions in their territory. Various types of trailers and truck beds for transporting horses and equipment to fires are illustrated and described in the *Fire-Control Equipment Handbook* (Anonymous 1946, pp. F-1 to F-5).

FIREBREAKS

A firebreak is defined (*Forestry Terminology* 1944, p. 32) as an existing barrier, or one constructed before a fire occurs, from which all or most of the inflammable materials have been removed; designed to stop or check creeping or running but not spotting fires, or to serve as a line from which to work and to facilitate the movement of men and equipment in fire suppression. The term "fire line" which in the past has been employed as a synonym is better restricted to the special lines which are made after a fire is started for the purpose of suppressing that particular fire.

Assistance in suppression is the primary function of firebreaks and justifies their construction prior to the fire season. Suppression is facilitated because the firebreaks furnish points from which fighting can be started without loss of time in building fire lines. One case cited by Wagstaff (1942) illustrates how firebreaks reduce suppression costs and damage. An 8-foot graded firebreak costing $20 per mile to construct and $3 per mile to maintain, located through grassland near the foot of a steep slope, reduced suppression costs from $215 to $45 per year, estimated damage from $244 to $25 per year, and area burned from 24 to 12 acres though the number of fires per year remained the same. As will be discussed later under suppression, Chapter 13, building fire lines ahead of a going fire is normally a necessary step in fighting the fire. Such lines are essentially different in character from the firebreaks established and maintained prior to the origin of the fire. Firebreaks are under consideration at the present moment.

Firebreaks when located beside traveled ways and properly constructed and maintained to fit local conditions may reduce the number of fires. In fact as used along railroad rights-of-way firebreaks are maintained because of their preventive function (see page 70).

In order that a strip in or adjacent to the forest may serve the purpose of a firebreak it must be cleared of the more inflammable material and be opened up sufficiently to permit easy progress for fire-fighters along the strip and to afford space for effective fire fighting, particularly when backfiring technique is employed.

It will readily be seen that the transportation system is in itself a network of firebreaks. For assistance in suppression there are no better firebreaks than roads and trails, although they are not the best for preventing fires from spreading. To be effective for this purpose the roads and trails must be bordered by special firebreaks.

Inflammable material which ordinarily is removed in preparing a firebreak consists of the litter and duff, ground cover, underbrush, reproduction, fallen trees, lower dead limbs on living trees, and standing dead trees.

A ground surface kept bare of vegetable matter is the ideal. This is not always practicable for the whole width of the firebreak but should be secured on at least a narrow strip down the center or along the edge.

At one time it was considered desirable that a firebreak be completely cleared of all standing trees. This idea is now abandoned in best practice. The most effective firebreak is one supporting a complete forest cover, which acts both to inhibit a luxuriant ground cover of herbaceous plants so likely to flourish on bare areas and to keep a higher moisture content in what litter and ground cover may persist under the shade. Both original construction costs and annual maintenance charges for such a strip are less than for one completely cleared, and also a more effective firebreak is created. By maintaining a forest cover over the firebreak the land is kept in production.

If the firebreak is narrow and is plowed rather than burned the effect on the growth rate of the area used as a firebreak would be insignificant. On a wide firebreak burned over annually or semiannually growth would be somewhat reduced, perhaps as much as a third.

Firebreaks vary in width from a foot or two to several hundred feet. The width more commonly falls either between 6 and 15 feet or between 50 and 100 feet, depending on natural conditions and the methods of construction and maintenance which can be employed.

The narrower type of firebreak is suitable if the entire width is to be cleared down to mineral soil. Where this method is used the expense of clearing a wide strip would be prohibitive. The wider type of firebreak (50 to 100 feet) finds application where the surface need not be entirely cleared of vegetable matter. In this case a narrow strip 2 to 4 feet in width is cleared on the outer edges of the firebreak and the territory between is burned broadcast. Ordinarily this burning removes most but not quite all of the duff and ground cover. This type is well adapted to conditions prevalent in the southern yellow pine regions. On the whole the tendency is toward the use of a narrow strip 6 to 12 feet in width which will have bare soil over practically its entire width.

Even in the South where wide burned lines are inexpensive to construct and maintain, narrow disked firebreaks up to 8 feet in width are preferred by some men. Special gang disk plows have been developed

for making this type of line at low cost. Firebreak construction in this region is less expensive than in other parts of the country.

The first disk plows developed made a line that, after reworking, became a ditch difficult to drive across. Later models have been developed that make a clean level firebreak 8 feet wide.

On sand plains in the Lake states narrow lines frequently are used, and on very hazardous areas a wider type with a graded 8-foot strip on each side separated by a wider cleared strip with a road down the middle for low-speed truck travel has been employed. This firebreak is constructed by caterpillar tractors and graders, and the two side strips are maintained by disking two or three times a year. The system blocks the area into mile squares and provides a transportation system as well as a network of firebreaks.

Meade (1944) describes a grader disk combining a grader blade and disk in one machine. The blade and the disk can be interchanged in the field. It is adjustable for depth, pressure, and cant, and also adjustable from side to side. The disadvantages are that it throws dirt only one way and must be transported by a truck.

The use of plows, graders, harrows and other equipment with horses and tractors for the construction of firebreaks has revolutionized their building and maintenance. Plowing and grading by machinery to create a cleared firebreak with a bare soil surface are quickly accomplished on rough, stony, brushy, steeply sloping forest areas without any preliminary clearing where a few years ago such work would have been deemed impracticable.

Firebreaks must receive attention at least once, often twice, and, rarely, more times each year if they are to be effective. Maintenance consists in harrowing or replowing the mineral soil portion of the strip and in burning over the remainder where firebreaks are used. There is a possibility that effective methods of maintaining firebreaks by the application of chemicals can be developed, thereby cutting present maintenance costs.

Chemicals effective in sterilizing the soil and killing the vegetation can be found, but they are expensive, poisonous, and dangerous to use. Bruce (1941) discusses the problem as encountered in the chaparral region of southern California. In this region firebreaks of expensive type are justified because of the extreme fire danger that may develop, the damage which fire causes by affecting runoff and by starting erosion and silting up of reservoirs, and the very high value of water. In the chaparral region, with a cover worthless for timber production, watershed protection justifies the construction and maintenance of at least

2500 miles of 40- to 100-foot wide firebreaks built at cost of about $800 per mile.

Experiments with 2,4-D are in progress (Blanchard 1947), and in the future methods of using this chemical for killing vegetation on firebreaks may be developed.

The principle in locating firebreaks is first to utilize all natural protective features such as lakes, rivers, streams, swamps (provided they do not dry out in the fire season), and cliffs, and also the existing or planned transportation system, roads, trails, stock driveways, etc., and to construct special firebreaks only where these natural and artificial features fail to meet the situation.

Firebreaks are improvements made primarily for fire control, and the construction and maintenance charges expressed as cents per acre protected can easily reach a figure out of proportion to the results secured.

The fire danger must be exceptionally great or costs remarkably low to justify a systematic gridironing by firebreaks of a forest property into areas even as small as 160-acre blocks. On most properties the use of firebreaks must either be the preliminary development of what ultimately becomes the road and trail system, needed for other purposes also, or be employed sparingly in critical locations.

Sometimes large cutover areas with heavy accumulations of slash should be divided into smaller and more easily protected blocks by firebreaks. Such firebreaks may be narrow plowed lines or more often will be wide strips upon which disposal of the slash has been made. This type of treatment is considered under fuel reduction, Chapter 10. Where a short length of firebreak will be effective in separating an area of high risk, such as a camp ground or resort area, from adjoining forest areas having a high hazard such firebreaks may be justified.

So many fires start beside railroads, particularly those burning coal or wood, that the use there of firebreaks usually is justified. Maintenance of the right-of-way in noninflammable condition has been mentioned as one of the measures for preventing railroad fires. This can be accomplished only by keeping a wide, carefully tended firebreak on each side of the track. The width advised for railroad firebreaks is from 100 to 125 feet on each side of the track. A strip 2 to 10 feet wide on the edge of the firebreak farthest from the railroad center should be kept bare to mineral soil and the remainder of the strip should be carefully burned over twice each year. As dense and thrifty a forest as possible should be preserved over the entire firebreak. When the firebreak is first constructed all dead trees and lower dead branches

should be removed as well as all inflammable underbrush and reproduction.

The safety strip recommended by the Pennsylvania Department of Forests and Waters (Wirt 1928) and the standard railroad firebreak which has been used in New Jersey are both examples of this type of railroad firebreak.

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CHAPTER 9

Presuppression: Equipment and Personnel

EQUIPMENT

Arrangements should be made prior to the fire season for providing all the tools, equipment, and supplies likely to be needed in combating fires. The type and quantity of the material that should be on hand vary widely with local conditions and include both hand and power tools. In general, all equipment should be of the types which local experience has shown are most effective. They should be provided in such volume as the past fire history and judgment indicate may be needed. They should be located at strategic points in the forest or at the headquarters from which the firefighters start. One excellent plan for hand tools is to distribute through the forest special tool boxes painted or labeled in a conspicuous manner and containing a complete firefighting outfit for a crew of the size likely to be available at the given location.

Ordinarily within a given locality dependence is placed upon a relatively small number of equipment items. This is because for the prevailing forest conditions only a few tools have proved highly effective and worth the trouble of bringing out to the fire. The choice of these tools may at times be influenced by local custom, unenlightened by developments elsewhere, and by the fact that the particular tools are on hand for other purposes, rather than that the tool used is the very best for the purpose. The trial of new tools from other regions still holds promise for many localities. Forest types serve as the underlying basis for real distinctions between the relative values of different tools for fighting purposes. For example, the equipment used in controlling fires on sand plains would be unsuited for fighting a fire burning in a peat-covered area.

In selecting equipment for firefighting not only must the right kinds be provided, but the right numbers of each kind of tool to equip a well-balanced crew for the method of firefighting they will use. It is well to remember that it is much better to have too much equipment at the fire than too little.

Considering the country as a whole there are a large number of equipment items which can be advantageously employed in some region or in some phase or method of firefighting. Godwin (1945) in an article entitled "The development of fire-fighting equipment since Pearl Harbor" listed 27 categories or groups (including both old and new equipment) which merit consideration. This illustrates the variety of equipment which finds use in fire-control operations. The author stresses the fact that many new developments in equipment are under way. Osborne and Cowan (1946) describe the equipment recommended particularly for the Pacific Northwest. The U. S. Forest Service *Fire-Control Equipment Handbook* (Anonymous 1946) divides the field into 19 groups and describes several items under each group. The grouping in this handbook is as follows:

- Fire-danger equipment
- Detection equipment
- Compass, protractor, and dispatcher equipment
- Communication equipment
- Photographic equipment
- Transportation equipment, vehicular
- Water-carrying equipment
- Packing equipment
- Hand tools and containers
- Fire line power equipment
- Pumping equipment
- Firing equipment
- Lighting equipment
- Camp equipment
- Subsistence supplies
- Medical and safety equipment
- Sharpening equipment
- Smokechaser and fire crew outfits
- Miscellaneous equipment

The handbook, though it reflects mainly U. S. Forest Service practice, gives the best presentation available of types of equipment useful over the country as a whole. Within the pages of this text it is not possible to enter into a listing and description of the numerous equipment items available. As opportunity offers, the reader should become familiar with the equipment used by federal, state, and private fire-control agencies operating in his locality.

What is attempted here is to recognize a few broad groups of equipment, employed directly in fire fighting, on the basis of the use to

which they are put in fire fighting and list with comment some of the more important items under each group.

Equipment employed may be grouped as follows:

Cutting and felling.
Raking, pushing, and beating.
Digging and fire line construction.
Application of water.
Backfiring.
Lighting.

Cutting and Felling Equipment

Axes, brushhooks, saws, wedges, and sledge hammers are usually employed. The saws, sledges, and wedges are needed only where there are many snags to be felled or down timber to be cut into logs in clearing fire lines. In most forest types either axes or brushhooks are useful, but both are not needed. The choice depends on size of the material to be cut. In other timber types neither an ax nor brushhook may be essential.

Bucksaws, Swedish type, may be needed on small timber while crosscut saws and power saws may be needed for felling snags and cutting large trees. It is only in heavy timber types or areas of windthrown timber, where a large amount of felling and bucking-up has to be accomplished quickly, that it will pay to use power saws in fire control. Several excellent makes of power saws are available.

Raking, Pushing, and Beating Equipment

Rakes of all kinds, Rich, Council, and McLeod tools, swatters, rotary fire mop, and Gravely fire-line broom are included. The Rich and Council tools have steel mowing machine blades which may be used for raking, digging, and cutting. The McLeod tool (also a combination of rake and hoe) is especially effective when raking in deep pine needle litter. The fire swatter is a strip of belting 12 inches wide by 12 to 18 inches long fastened to a steel shank and mounted on a hoe pattern handle. It is effective because of its smothering action for beating out fires in grass and similar light fuels. The steel shank can be replaced by a scarifier and the swatter used as a rake if necessary.

The rotary fire mop is a revolving swatter with 6 rubber mats or flaps which, as the mop is rolled along the fire edge, rotate and beat out the fire (Murphy 1946). The swatter and rotary mop are modern

improvements over the old system of beating out the fire edge with a pine bough.

The Gravely fire-line broom (Howard 1946) consists of a Gravely tractor with rotary broom attachment which clears a fire line 18 inches wide in open types where the materials to be removed are principally fallen hardwood leaves and pine needles.

An asbestos mat at least 6 by 8 feet in size may be dragged by truck or horse power over the edge of a fire burning in grassland. Two mats one behind the other will usually extinguish a grass fire (Anonymous 1946, p. J-8).

Digging and Fire Line Construction Equipment

Long-handled shovels, mattocks, and hoes of all kinds, particularly the adz hoe (Osborne and Cowan 1946, pp. 2–3), and Pulaski tool cover the commonly employed hand tools. The long-handled shovel is indispensable where dirt is to be used in extinguishing burning material and wherever there is much digging out of the fire edge to be done. Under most circumstances hoes are better than the shovel for digging a fire line down to mineral soil. They are also superior for cutting and raking. The Pulaski tool is a combination ax and grub hoe and is a better cutting tool than the hoe. The shovel may be used for beating out a fire. The mattock is a clumsier tool than the grub hoe and in spite of its extra cutting edge is rarely chosen.

Power equipment if available will cheapen the cost of digging fire lines by hand. Such equipment includes a wide variety of plows, graders, bulldozers, angledozers, trailbuilders, and brushbusters. Small, relatively light trenchers, such as the Michigan linebuilder and the Bosworth trencher (Wicklund 1940), are being developed. In contrast, heavy units operated by crawler type tractors weighing many tons are useful under certain conditions. As yet mechanical equipment for fire line construction is passing through a period of rapid development and eventually more or less standard types of equipment may be developed to fit specific forest types and topographic conditions. This situation is well summarized in the U. S. Forest Service *Fire-Control Equipment Handbook* (Anonymous 1946, p. J-1).

Plows for fire line construction have been developed to fit conditions of soil, cover, and topography in nearly all parts of the country. Several of these plows are listed in the *Fire-Control Equipment Handbook* (Anonymous 1946, pp. J-2 to J-7). Hartman (1947) describes the development and use of one of these plows (the Ranger's Pal)

suited for use in the longleaf pine region. He shows how the costs of fire control have been reduced since the introduction of the Ranger's Pal.

A new light-weight plow not listed in the handbook is the Aamodt stubby plow (Aamodt 1947).

Application of Water

Equipment for applying water to fires includes water bags and cans of all sorts, back-pack pumps, power pumps, of several types from light to heavy, and tank trucks, hose, and well-digging outfits.

Back-pack pump outfits, such as the Smith-Indian, holding 5 gallons of water and hand operated with a trombone pump are widely used throughout the country. They furnish a more mobile means of applying water although in lesser volume than power pumps. Small force pumps can be secured in a variety of styles. The best types are those in which the water container is carried comfortably on a man's back, leaving his hands free to operate the pump and direct the water spray upon the fire. The advantage of water bags over metal cans is that they are lighter and can be transported and stored in small space. The metal cans, however, will stand alone while full of water, and they are usually considered preferable to water bags.

As road systems develop, power pumps are put to increasing use. The light portable ones can be carried in from the roads. The heavier pumps are mounted on trucks or on trailers pulled by tractors and operate in territory accessible by roads.

Several makes of portable power pump are manufactured especially for forest firefighting purposes. These pumps vary in weight from less than 40 to about 700 pounds. The heavier ones are designed for use close to main roads; the lighter types may be packed far back into the woods. Power pumps may be classed as rotary, piston, plunger, or centrifugal. The rotary pumps develop high pressure and adequate volume even in small sizes and are light, compact, and self-priming. They have serious defects, such as the rapid wearing out of the rotors which are expensive and cannot be changed in the woods, and they have a speed too great for long life and reliable performance.

Weight is the principal disadvantage of the piston and plunger type of pump. However, when correctly maintained these units can be taken into very rough country. They are the most reliable type of pump for forest fire service. The centrifugal pumps although small, light, and compact cannot produce high pressure. They can be used

with dirty water since grit has little effect on the working parts. Performance and reliability in a power pump are more desirable than lightness.

The development of a network of water holes, each holding several thousand gallons of water, at frequent intervals is a presuppression improvement worth putting in where running streams do not furnish abundant water supply well distributed over the forest areas. The water holes are best located beside truck roads.

Tank trucks equipped with pump, tools for a firefighting crew, and sometimes space to carry a small crew have been developed in all parts of the country. A few illustrations are cited:

Smith (1947), Penn. Dept. Forests and Waters, a ½-ton pick-up with a 110-gallon tank, Panama pump, 400 feet of hose, and tools for 15-man crew.

West and Mattsson (1947), Wasatch National Forest, a tractor-tanker and a ¾-ton weapons-carrier tanker, both with high-pressure fog.

Fortin (1947), Ouachita National Forest, a stake-body truck with Panama pump, a 165-gallon tank, 500 feet of hose, tools, and subsistence supplies for 25 men.

Rowland (1946), Army Air Force proving ground in Florida (formerly Choctawhatchee National Forest), a variety of tankers, pump outfits, and trailer tankers to meet the high fire danger on this area.

Cherry (1941), Massachusetts Dept. of Conservation, describes the construction and use of a 1000-gallon brushbreaker tank truck for the special conditions on the sandy, brush-covered, wind-swept lands of Cape Cod. Here crown fires start easily, and, in the tangles of scrub oak brush, hand tools and hose lines are hard to use. The essential features of this brushbreaker are the chassis and engine, front bumper and guard rails, water tank, and pumping equipment. The chassis has 10 wheels, 2 front and 8 rear, and can go anywhere through the woods. The truck is completely protected with armor so that it can knock down trees without injuring the truck. It can make a speed of 60 miles an hour on surfaced roads. The bumper is so designed that the initial impact and crowding action take place 5 feet from the ground.

The plunger type of pump has a 50 gallon per minute capacity and 400-pound pressure. The tank holds 1000 gallons. A second pump of the rotary type can fill the tank at 200 gallons per minute. The nozzles can be regulated from a fog to a solid stream and have trigger control. In addition to these nozzles, which are worked from the truck, two 500-foot hose lines are carried. The crew consists of 6 men, one of whom is a road or trail locator as the truck drives along the edge of the fire.

The cost of the truck was $6000. Its use has had a profound effect on the firebreak system. The forest areas had been split into half-mile squares with 40-foot firebreaks around each unit. These firebreaks often failed in emergencies. Now it is felt firebreaks should not be built, but fires should be fought by the brushbreaker tank truck.

Backfiring Equipment

Torches, flamethrowers, and fusees are employed. Some convenient means of setting backfires is wanted when fires are fought by backfiring. If many backfires have to be set, a torch should be carried instead of relying solely on matches. The type made from gas piping with a wick in the end and burning kerosene oil is commonly employed. Frequently one of the heavier types of torches burning kerosene, gasoline, or liquid gas under pressure, which produces more heat and therefore starts the backfires more quickly, is needed. All torches must be provided with fuel.

At least one of the plows used for fire line construction in southern pine types is equipped with a flamethrower which projects a flame 3 to 6 feet long on either side of the plow as it moves along the line. Perkins (1941) describes a portable flamethrower developed for use in backfiring southern California brush fields. It can be transported on mule back or by two men.

Railway signal fusees have been tried as torches for backfiring but did not provide the volume of heat desirable. A special fusee or forest fire torch of the same general type as the railway signal fusee is on the market and has proved satisfactory.

Lighting Equipment

For night firefighting, devices for furnishing light are needed. The fire itself dies down at night and does not furnish adequate light. Headlights which can be attached to the firefighter's cap provide the most satisfactory light since they will be placed by the turning of the man's head on the spot where light is wanted. Such headlights can be secured, operated either by flash-light batteries or by carbide lamp. Lanterns, except as an aid in walking through the woods, furnish poor assistance in firefighting.

Floodlights, electrically or gasoline operated, are available. The gasoline floodlight can be set on the ground with a powerful light on standard above. Electric light outfits can be placed on small rubber-tired trailers built to permit one man to haul lights along the fire line (Anonymous 1938, pp. 193–194).

PERSONNEL

Other presuppression activities have been developed in order that the firefighters may arrive at the scene of the fire at the earliest possible moment after its inception and that, when they do arrive at the fire, they may find conditions for its control as favorable as human forethought can provide.

The problem facing the personnel of the fire protective organization is to vitalize the preparations which have been made and to take full advantage of the opportunities offered. The quality of the personnel can be shown in two ways: first through the ability with which they have planned and carried on the task of fire prevention and presuppression activities, and finally through the skill and efficiency with which they suppress fires.

Just as careful arrangements prior to the start of the fire must be made to insure adequate man power as to provide transportation, communication, and other improvements. Adequate man power has sometimes been thought of in number of men. Far more important than mere numbers is the quality of the personnel, particularly their ability to apply, skillfully, existing knowledge concerning fire control. Fire control in its various aspects requires physical strength, technical skill in firefighting, and executive ability of high order. Poor men frequently satisfy none of these requirements. Without training, men cannot function satisfactorily as cogs in a forest fire organization. Too serious consequences may come from using inexperienced men. This is now so well realized that the tendency is to make the men charged with fire control a part of the year-long force.

Where an organization must be expanded during the fire season (beyond the detailing to fire control of members of the permanent force), so far as possible the same temporary men are taken on year after year. This principle holds even when applied to relatively loose organizations such as the local fire warden system of an entire state. Since men skilled in firefighting and other phases of fire-control technique are scarce, large organizations find it to their advantage to offer training both to their present employees and particularly to new members of the force. The training must be adapted to the position which each individual is to fill, from the untrained labor right on up through the ranks to the members of the overhead staff. Many members of a fire-control organization work alone much of the time, and ability to exercise initiative and to take responsibility are valuable qualities to

develop as well as efficiency in the routine performance of their duties.

The detection of fires is taken care of by special men—the lookout observers. Similarly the actual work of firefighting should be provided for by assigning men specifically to this task during the fire season. Some men may do nothing else but remain at headquarters close by a telephone ready for an instant start. Others, equipped with a portable radio for communication with headquarters, may patrol and assist in detection until needed for firefighting. Sometimes it may be effective to scatter small crews through the forest and keep them at work on forest improvements until called to a fire. The employment for fire suppression of trained fire crews continuously subject to call and paid on a daily or a monthly basis during the fire season is one of the best means of obtaining competent men for fire suppression. This plan has already been put into practice in various parts of the country.

Training is carried on systematically year by year by practically all fire-control organizations in the country, particularly by the U. S. Forest Service. During the war the national director of Civilian Defense sponsored the establishment of the Forest Fire Fighters Service organized to train and equip volunteer firefighters and to strengthen the forest protection agencies in the various states. This Service was taken up actively in many parts of the country and resulted in training thousands of young people mainly of high-school age in fire prevention and suppression.

On account of the smaller resources at stake per unit of area, the firefighting personnel in the forest cannot be developed to the degree of intensity found in cities. However, even today the same principles of quick action by a thoroughly trained personnel specializing in fire control, as exemplified in the city fire department, are fundamental in developing effective forest fire control.

So far as possible, hiring of large numbers of untrained men should be avoided, although sometimes it may be inevitable. An increase in the personnel used on prevention and presuppression activities and in the number of organized fire crews will increase the number of trained men available in an emergency for firefighting and also will result in a decrease in the number of big fires where large numbers of men are needed. Eventually it is hoped that all forest firefighting will be done by the regular organization and that no untrained men will be employed.

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CHAPTER 10

Presuppression: Fuel Reduction and Fuel Mapping

FUEL REDUCTION

Since there can be no fire without fuel upon which it may feed and since the severity of a fire is dependent upon the fuel available, it is logical that the possibility of reducing the amount of inflammable material should receive careful consideration as a presuppression measure. The entire forest is potentially fuel that, if dry enough, may be consumed. However, it never dries out completely, and the different classes of material in the forest characteristically show a wide variation in the degree of inflammability.

In reducing the amount of inflammable material only measures of a practical nature can be considered. Certainly all inflammable material cannot be eliminated without unwarranted expense. In this connection particular consideration should be given to those materials constituting a definite hazard, i.e., fuels that form a threat either because of special suppression difficulty if ignited or of probable ignition because of their location. A heavy accumulation of logging slash or an area having many long-standing broken-topped snags are illustrative of the first condition, while the second occurs along railroad rights-of-way.

Fuel Reduction Methods and Classes of Fuels

In Chapter 4 (page 40) the material in the forest which may be potential fuel for forest fires has been classified in seven groups. When these classes of potential fuel are considered in relation to the spread and severity of fires, radical differences are apparent. The living por-

tion of the forest itself even under particularly favorable conditions for burning, such as extreme dryness, high temperature, and strong winds, is almost immune to severe damage from forest fires unless other classes of inflammable materials are present in quantity and make possible a conflagration which will destroy the living trees. The reduction of inflammable material in the forest resolves itself, therefore, into treating the other six classes of potential fuels in such a way that the living portion of the forest itself is reasonably safe from harm.

In considering what should be done with these other classes of material, it must be remembered that the cost in relation to the value of the resource at stake either on the area involved or on adjacent areas has a direct bearing upon what should be done to reduce the amount of inflammable material. It should be understood that there may be better ways of effecting this reduction than the removal from the forest of the material in question, or than its disposal by burning or by other direct means within the forest itself.

The maintenance of a dense forest will do much toward keeping both the live and dead material within the forest so moist that it does not become dangerously inflammable. This is the ideal way of accomplishing the reduction of inflammable material in many forest areas. However, it will not be effective everywhere and, of course, cannot be used on areas where cuttings have been made. Here the forest has been opened up. However, with light partial cuttings the openings may not be large, and much may be done even after such cuttings to retain a forest cover which will keep down inflammability appreciably.

A greater use of the unevenaged form of forest will protect the ground cover and litter from excessive desiccation and will maintain conditions of lower inflammability than occur on the present clearcut areas. Since the benefits of these measures can be obtained only gradually, immediate action to bring about a fuel reduction along other lines should be taken.

In general, on firebreaks all inflammable materials except the living trees should be removed. Sometimes removal on a strip alongside roads used as firebreaks is justified for some classes of material. On the whole, any work involving direct reduction of any inflammable material must be justified before being undertaken.

Underbrush. Usually it is impractical to spend money for cutting and removing the underbrush. In fact these plants may serve a very useful purpose in maintaining proper soil moisture conditions, retarding erosion, and preventing the forest litter from becoming too inflammable. A fully stocked forest, in contrast to many of the present

understocked stands, will keep underbrush down to a desirable minimum.

Living Ground Cover. So often the living ground cover consists of forage plants. Frequently without expense domestic animals, or sometimes wild animals, keep this forage grazed so low that it is noninflammable. An example of the value of grazing in this connection has been described by Ingram (1928).

Forest Litter and Undecomposed Humus. Only exceptionally will it be justifiable to dispose of the forest litter and undecomposed humus as a forest protection measure. In the first place this material if possible should be retained in the forest to conserve and enrich the soil. The litter is extremely important in this connection, and its removal usually is justified only toward the end of a rotation, when, for the purpose of establishing regeneration, the seedbed conditions may be improved by the removal of the forest litter and undecomposed humus. Its removal as a fire protection measure is in general too expensive even if it were not bad silviculture. Special conditions, however, allow exceptions to this general rule.

The annual or periodic burning over of forest areas as a fire protection measure was used by the lumbermen and forest landowners, even before organized fire control was initiated, for the purpose of protecting standing timber against fire. The term "light burning" arose in connection with such operations. It has come to have the meaning of an intentional use of surface fires allegedly to keep the ground free of inflammable material made up of the litter, undecomposed humus, ground cover, underbrush, and reproduction. The original theory of this operation was that, if a light surface fire could be run over a forest area at a favorable time, the ensuing fire would (1) do little or no damage to the standing timber and (2) at the same time consume the inflammable material in the forest which might, if left unburned, provide fuel for a more serious fire accidentally starting at a more dangerous time. These premises, though plausible, usually prove to be unsound. From the silvicultural standpoint light burning has an injurious influence upon the productive capacity of the site. However, at this point only the question of its usefulness as a fire-control measure is under discussion. After the average light burn enough inflammable material is left to make possible a severe fire on the same area.

Oftentimes trees are either killed outright by the light burn or so seriously injured as to die within a relatively short time afterward. The amount of inflammable material is thereby increased. If, how-

ever, the fire is so light that no damage results to the standing trees, then certainly an abundance of inflammable fuel must remain. Conversely, if the burning is made heavy enough to consume all the inflammable material available, then appreciable damage results to the living trees and, as pointed out above, additional fuel is made available for subsequent fires.

Theoretically, it should be possible to burn over a forest with a light fire and avoid serious injury to the trees. To do this requires so much time, and must be repeated each year in order to prevent the accumulation of fuel in the form of the annual leaf litter, and dead grass and other herbaceous materials, that the method becomes an expensive form of fire protection.

In applying light burning correctly careful work is needed. It requires that the litter be raked away from the base of the trees so that the fire shall not come in direct contact with these trees. This alone is a time-consuming and costly operation where large areas are involved. If only the protection of an existing stand of timber is desired, an annual light burning under which the trees are safeguarded against potential basal wounding as just mentioned may prove satisfactory. However, where the continual production of forest crops is desired, annual burning cannot be allowed.

Light burning has been practiced chiefly in the forests of California and in the southern pineries. In the mixed coniferous forests of California this method of burning is entirely out of place. In that region light burning has proved a failure from its forest protection premise and in addition has been the cause of serious forest deterioration by which large areas of once highly valuable timberlands have been converted into worthless brush fields (Show and Kotok 1925). The sentiment favorable to light burning which existed in California in the past has now been overcome, and there the method has fallen into disrepute.

In the Deep South, annual or periodic burning over of forest areas is still favored by the sentiment of the people. There are a variety of reasons for this which are discussed in a previous section (page 28). As long as the present sentiment remains unchanged in that region, it may prove impractical in the face of adverse climatic conditions to get along without burning over the forest at periodic intervals. These intervals should not be annual, but should come 2 to 4 years apart. This prescribed or controlled burning should be carried out during the winter season on specially selected nights when the danger of an intense injurious fire is reduced to a minimum. Such fires should be confined to stands of longleaf pine which is a fire-resistant tree even in the seedling

stage, but which can be destroyed by fires occurring where there has been no burning previously for several years and a "deep rough" or accumulation of pine needles, grass, and other vegetation has formed. Even though the longleaf pine is located on deep sand which represents the soil type least likely to be injured by continuous burning, still, in the long run, the productive quality of the site may likely be lowered by these periodic fires.

Periodic burning to reduce the chance of disastrous fires has been practiced successfully for many years with chir pine in India (Gorrie 1935) under conditions somewhat similar to those prevailing today in the longleaf pine type.

Dead Branches and Moss. The removal of dead branches and moss from all trees throughout a forest is an unwarranted expense except on firebreaks and sometimes along roads.

Snags. Where the fire risk is high, as in areas subjected to many lightning storms, snags should be eliminated. They are such a potential menace for the rapid dissemination of fire that the cost of getting these snags down is fully justified. It is good practice to get rid of such dead trees throughout the forest. Various methods of felling snags have been tried, including sawing, burning down, and blasting. In one experiment in the Pacific Northwest (Munger and Simson 1929), blasting proved cheaper than sawing by approximately 20 per cent, the greatest difference being found with the largest snags; burning proved less certain and hence was most expensive. In this connection Johnson (1947) has called attention to the use of various army explosives for this purpose. In experiments elsewhere than in the Pacific Northwest and under different conditions snags have been cheaply burned down in the winter.

Power-driven saws capable of felling large snags make it possible to get rid of such large materials at a much lower cost than when sawing is done by hand.

Oregon has in force a snag-felling law which applies to most of the heavily forested country west of the Cascade Mountains. Under the provisions of this law (Ferguson 1935) in areas of green timber all snags must be felled. On areas where all the merchantable timber is cut, all snags more than 25 feet tall and 16 inches in diameter must be felled providing that the number per acre to be felled does not exceed the average number of snags found in the green timber. On most national forest timber sales, the operators are required to fell all snags above a minimum size.

Logging Slash. The slash left after lumbering operations is the chief class of inflammable material the volume of which needs radical reduction. In itself, slash reacts beneficially on the forest by adding, through decay, to the organic material in the soil. On many cutover areas the danger of fires gaining momentum in the slash is so great that in the present stage of forest protection some type of slash disposal must be undertaken. However, the tendency today is to recognize that, even though the fire danger would be greatly reduced by disposal of all logging slash, yet this may not be the cheapest way of furnishing protection.

In some forest types slash as an inflammable material can be sufficiently reduced simply by encouraging grazing. Domestic animals break up the slash to some extent, and they keep browsed down the herbaceous materials which often become inflammable and carry fire from one windrow of slash to another. Firebreaks of a sort sometimes can be created by properly arranging stock driveways at intervals throughout the cutover area.

The close utilization of defective material should be practiced on all cutover areas as this often will reduce the volume of slash considerably. In the Pacific Northwest, the conditions of inflammability may be so great at certain times of the year, that, in addition to a careful clean-up of slash and other inflammable debris around all camps and logging equipment, the actual wetting down of the ground daily around steam donkey engines is advisable (Munger 1927, pp. 19–20). There may be other regions where similar action would occasionally be worth while although such a measure usually is not justified.

In a number of states the disposal of slash along highways, along railroads, and in a narrow zone along property boundary lines is required by law, whereas in other states disposal of slash over the entire cutover area is required. Information on this matter, as well as on other laws concerned with forest fires, for individual states generally is readily available in the compilation of state forest fire laws issued by the separate state forestry departments. Where laws relative to slash disposal exist they should be so worded that no one single method of disposal is required; instead the method should be left to the discretion of the proper state forestry authorities. In this way the particular needs of local conditions can be met and the inelasticity of fixed regulations avoided.

In deciding to what extent the disposal of slash is required on a given tract it should always be remembered that very frequently it is not the slash itself which is responsible for the start of a fire. Ordinarily, the

litter, which usually is dried and more readily ignited than the slash, is the fuel which spreads the fire. Once started, however, a fire will burn more intensely in accumulations of slash and may develop more momentum in spreading into adjacent green timber. It is questionable whether actually any more fires per unit of area start in slash-covered areas than in those not so covered. Furthermore, the cutting in itself causes a change in local climate toward a drier condition that makes the area more inflammable, entirely regardless of the presence or absence of the slash. These points should be borne in mind in considering whether expenditure is or is not justified for slash disposal.

The following are the standard methods employed in reducing the volume of logging slash.

Piling and Burning Slash. For securing a relatively complete disposal of slash, a standard method consists in placing it in piles and then burning these piles. One way of doing this is to wait until after the logging operation is finished and then cut the tops while they are relatively green into a convenient size and pile them. The piles are left intact until a season in which climatic conditions favor both the burning of the slash and the safety of burning, when they are burned in a separate operation.

Good technique is required to build slash piles that will stand for several months to a year and that then are still easily ignited and completely consumed by fire. The details of making satisfactory piles vary with the tree species in question. In general, only the small material in the tops is placed in the piles, while all pieces with top diameters above 4 inches are left on the ground to decay. The small branches are the ones which constitute the fire hazard, and these only are piled and burned. The locations of the piles must be carefully selected so that, when the piles are fired, neighboring trees and patches of reproduction will not be burned.

In regions where snowfall can be counted upon in winter, the most effective time to burn is the late fall just after a light blanket of snow which covers the surface but has not sifted solidly through the piles. The principle under this condition is to burn when the adjacent ground and trees are damp but the center of the pile is still dry, will ignite readily, and will continue to burn. It is essential in piling slash that some of the finest and dryest material be placed in the center but where it can be reached with a torch and easily ignited.

Piling and burning is a relatively expensive method of slash disposal, exact figures varying widely according to the difference in conditions and species to which it is applied. There are comparatively few forest

types where the fire danger justifies the expense of piling and burning or swamper burning all the slash.

Swamper Burning of Slash. Another method of piling and burning slash, but in one rather than two operations, is termed swamper burning. It is also known as progressive burning, burning as the logging proceeds, live burning, or forced burning—all these being names for the same general type of operation employed in different parts of this country or with some slight modifications.

In swamper burning, fires are started in convenient places while active logging is still taking place on the area and the tops are thrown on these fires and consumed as they are piled. This, of course, may be done at the time the trees are felled and bucked-up, or it may be left until the logs have been skidded from the area. It should not be delayed too long, as handling the slash becomes more expensive as it dries out. On the whole, there are advantages to swamper burning which indicate its use in preference to the piling and burning method in many instances. While swamper burning costs slightly more than ordinary piling and burning it has the advantage of actually burning over less of the area and consequently also doing less damage to the reproduction and larger remaining trees (Munger and Westveld 1931; Anonymous 1934). Obviously the method cannot be used during the season of the year when it is not safe to start any fires.

Broadcast Burning. This method, as its name implies, consists of setting fire to the slash and allowing the fire to run over the entire area. It is naturally the least expensive in direct cost of any of the slash-disposal methods costing only 2 to 5 cents per thousand feet board measure of logs cut. On the other hand, it is extremely destructive to the trees on the area and hence is suitable only to areas where clear-cutting has been practiced. The details of applying broadcast burning vary, but on the whole the method requires extremely careful and precise planned work on the part of the organization doing the burning. The reason for this is that the method is potentially in itself a great source of combustion and it is quite possible that the fire running over the area may escape to the adjacent green forests.

Fires should not be started directly on the edge of a clearcutting but preferably back far enough from the edge to create a draft inward and away from the surrounding timber. Only after these fires are well started should backfires be set at the edge of the clearing.

Davis and Klehm (1939) working in the western white pine type advise the method termed "center burning" be used on flats and slopes up to 30 per cent. In this method, a series of fires is first set in a zone

through the center of the area. When they are burning well, a second series of fires is started 100 to 200 feet inside the boundaries of the clearcut area. The effect of center burning is to create an upward draft in the interior of the clearing which sucks the flames of the central fires as well as those from outer fires in toward the center rather than allowing them to blow toward the edges of the clearing. The fires gradually burn outward from the outside row of fires to the edges of the clearing, but because of the strong draft in the interior these fires do not seriously threaten the adjacent timber.

On slopes steeper than 30 per cent, these same authors recommend setting fires in progressive strips. First, a narrow strip is burned off at the top of the slope, and then when this upper edge is well burned out, a second string of fires is set 100 to 200 feet lower down the slope. In this manner the entire clearcut area is progressively burned over.

Broadcast burning is best done in the fall (Anonymous 1933) at the beginning of a rainy period when the body of the slash is thoroughly dry after being exposed throughout the summer, but the atmospheric moisture is relatively high and gives every indication of tending to become higher in the immediate future. The fires are set in the late afternoon or early evening. Pressure torches or portable flamethrowers will prove of value in getting plenty of fire started quickly, a factor that contributes to the prompt creation of the inward draft so essential to safe broadcast burning.

Since broadcast burning is a menace to the surrounding timber, an adequate force of men equipped with firefighting tools should be on hand during the burning. In some forest types it may be necessary to construct fire lines in advance when broadcast burning is used. This is an expensive part of the method and should be kept to the lowest possible minimum. However, with men skilled in broadcast burning there is often little need of constructing many fire lines.

Broadcast burning will prove useful as a method of fuel reduction not only on clearcut areas with logging slash, but also on burned-over areas where a large volume of standing and fallen dead timber remains and on areas containing only decadent stands of undesirable trees, on which new plantings of better species are desired. The standing dead or living trees should be felled and then the entire area broadcast-burned. Areas of windthrown and insect-killed timber may be similarly treated, providing that reproduction has not already started.

A modification of broadcast burning is known as "spot burning." In this method, instead of burning over the entire area, only those patches where the slash lies densest are broadcast-burned. Elsewhere the slash

is left untreated. This method takes advantage of the low cost of broadcast burning and at the same time it does away with its undesirable feature of running a fire over the entire cutover area. A special adaptation of spot burning described by Colvill (1946) and Weaver (1946) is of particular interest because it introduces the element of mechanization in slash disposal with its usual attendant lowering of costs by using tractors equipped with slashbuncher-teeth blades to bunch the slash into compact piles. The cost of slash bunching with such tractors averaged around $8 per acre whereas hand piling under similar conditions may cost up to $15 per acre and includes only material under 4 inches in diameter.

Lopping, and Lopping and Scattering. Instead of being burned, the slash may be lopped into pieces of convenient size, and these may either be left as they fall or be scattered more or less uniformly over the area. This method does not accomplish an immediate reduction in the amount of inflammable material in the slash and hence is a less conservative measure from the fire standpoint. However, it is not without some value as regards fire control. The lopping of the slash into small pieces will enable firefighters to construct fire lines through the area more quickly and cheaply than if the material were left uncut. Sometimes slash, particularly of coniferous species, may rot faster when lopped and scattered in close contact with the ground. Thus, the hazard will be reduced more quickly than if no disposal at all is attempted. This method is best suited after partial cuttings and where a burning method is undesirable. It is at least half as expensive as piling and burning.

Partial Disposal of Slash. The high cost of slash disposal by the methods so far considered (with the exception of broadcast burning on clearcut areas, a type that is usually very cheap) is so great that ways of reducing the cost have been sought. As the result partial-disposal methods have been developed and are being used on an increasing scale. The principle here involved is to obtain relatively complete disposal of the slash over a portion of the area, and to leave the slash untreated on the balance, which is usually from 75 to 90 per cent of the entire area. The average cost per acre of slash disposal by this plan is greatly reduced. Broadcast burning is so destructive of reproduction and other standing timber as well as injurious to the soil that only rarely can this cheapest method of slash disposal be employed.

The partial-disposal method advised (Munger and Westveld 1931, pp. 45–50) for the ponderosa pine region in eastern Oregon consists

of piling and burning the slash on approximately 15 per cent of the cutover area arranged in strips about 200 feet wide, gridironing the area into irregular blocks. Strips of a similar width are treated alongside high-risk zones such as railroads, highways, and camps. Except on these strips the slash is left untouched.

This disposal of slash on the ground is supplemented by a more intensive system of detection and patrol, and other arrangements for suppression than would otherwise be provided during the succeeding 15 years needed for the untreated slash to decompose to a condition when it no longer need be considered dangerous. The costs of this partial-disposal method were estimated (based on labor wages prevailing around 1931) to be 22 cents per thousand feet board measure of logs cut. In this estimate there was a charge of 8 cents for the direct treatment of the slash and a charge of 14 cents to take care of the additional special protection measures lasting only 15 years. This cost of partial disposal stands in marked contrast to an estimated cost, also around 1931, of 45 cents per thousand feet board measure for piling and burning of all the slash. It is evident that the partial-disposal method cuts the cost in half and at the same time provides for better future protection of the area thus treated.

FUEL MAPPING

The Need for Mapping Forest Fuels

The location, amount, type, and condition of the potential fuel in the forest are fundamental in the planning of all fire-control activities. Such information is needed, for example, in conducting any systematic effort to reduce the volume of inflammable materials by any one of the methods discussed in the foregoing section. The greatest value of this knowledge, however, lies in the fact that it enables one to estimate before a fire occurs, under a given degree of fire-danger class, the speed and strength of attack that will be needed to control the fire within the time standard in question (Hornby 1935).

The Fuel Type

Logically, information on fuel conditions for any specific forest area should be in the form of maps. This first necessitates a determination on what basis fuel conditions should be judged in the field with respect

to their effect on fire danger. For this purpose the relatively simple classification of inflammable materials in the forest as outlined in Chapter 4 (pages 39 to 41) cannot be used for several reasons. In the first place, with the possible exception of pure grass types, the fuels on forest areas are not homogeneous. At the very minimum they contain at least living trees and forest litter. In the overwhelming number of cases other classes of fuels are included also, each of which has its own particular effect on fuel conditions. Secondly, even where there is uniformity in the classes of inflammable materials between forest areas any variations in amount and condition of the separate fuels destroys the comparability. Finally, as has been pointed out repeatedly, fuels alone are not the sole criterion of fire behavior.

That there is a direct correlation between fuel conditions and the rapidity of spread of fires has long been recognized. For this reason, the rate of spread was used in the first attempt by Show and Kotok (1929) to devise a workable index of fuel conditions for the northern California forest region. Using forest cover types as the index to fuel conditions which reflect to a high degree the many variables that together determine fire behavior (the vegetation and its fuels, climate, and topography), they found from records of actual fires the following differences in the average rate of spread expressed as area burned over per hour:

Cover Type	Rate of Spread in Acres Burned per Hour
Fir	1.07
Mixed conifer	3.79
Sugar pine-fir	4.33
Ponderosa pine	8.18
Douglas-fir	8.20
Woodland	12.58
Brush	13.79
Grass	23.73
Chaparral	55.00

These figures illustrate very nicely how differences in fuel conditions are reflected in variations of fire behavior. The fir type with its deep duff fuel has characteristically slower-burning ground fires, whereas burning in the brush and chaparral types is largely through the tops of relatively low, highly inflammable hardwood crowns resulting in extremely rapidly advancing crown fires. The high rate of spread in the grass type is common for surface fires feeding on dry grass and weeds, whereas the relatively lower rate of spread in the conifer types

is usual for surface fires burning largely in needles and small branchwood in contrast to a flashy fuel like grass.

It will be noticed that Show and Kotok expressed rate of spread in terms of area burned over per hour. Although this method of indicating fire behavior proved exceedingly useful in setting up hour-control standards it loses sight of the very significant fact that work in controlling a fire is essentially confined to its edge or perimeter, and not to its interior or gross area. This fact, though dimly recognized in the past, was not emphasized until 1935 when Hornby (1935; 1936) developed a system of classifying and mapping fuels in the northern Rocky Mountain region.

Hornby has indicated his principle of fuel classification clearly in the following statement: "The rate a fire will spread determines how many chains of fire line will be produced per hour. The difficulty of fire fighting caused by slope and soil, together with amount, size, arrangement and species of fuel along the perimeter of the fire, determines how many man-hours of work will be required for each chain of fire line. Evidently the man-hours per chain multiplied by the number of chains to be worked gives the fire fighting job to be done. Fuel maps will show, according to the mapping legend the probable *rate of spread* and the *resistance to control*" (Hornby 1935, p. 67).

From this dual designation in classifying fuels has arisen the fuel-type concept which has been defined as "an area of vegetation having definite forest-fuel, topographic, and soil characteristics denoting a specific rate of spread of fire on an average bad fire day and a specific resistance to the constructing and holding of control line" (*Forestry Terminology* 1944). Its advantage over cover type as an index to fuel conditions is that attention is focused on the two cardinal factors affecting fire suppression—the rate of fire spread and the difficulty of suppression at that part of the fire where control action is largely concentrated, the perimeter of the fire.

From an analysis of the records of 8789 fires which burned in various forest types in the northern Rocky Mountain region between 1921 and 1930, Hornby found that on average bad fire days (fire-danger class 5) the average rate of spread in perimeter ranged up to 18 chains per hour and that for the same burning condition the resistance to control in length of held fire line constructed per man-hour varied up to 3.2 chains. Instead of associating timber types with their respective rate of spread and resistance to control, four classes of each of these variables were recognized and values assigned to each class as shown in the table that follows.

DUAL CLASSIFICATION OF FUELS ACCORDING TO PROBABLE RATE OF SPREAD AND PROBABLE RESISTANCE TO CONTROL ON AVERAGE BAD FIRE DAYS
(Hornby 1936, p. 65)

Rate of Spread	Increase in Perimeter in Chains per Hour	Resistance to Control	Length of Held Line Constructed in Chains per Man-Hour
Extreme	18	Extreme	0.2
High	10	High	0.8
Medium	8	Medium	2.0
Low	6	Low	3.2

Using this system, standard ratings were established for forty-three fuel conditions typical of the northern Rocky Mountain region as to probable rate of spread and probable resistance of fire to control. These standards were used in classifying and mapping the fuel types within the timber types on some 15,000,000 acres of national forest and cooperative forest lands in western Montana and northern Idaho. In rating the fuel types, the rate of spread was considered to be influenced chiefly by four factors, namely, tree or brush cover, slope and topographic shelter, forest type, and previous burning, cutting, and blow-down. The important elements affecting resistance to control were indicated as the fine fuels present in standing green timber, snags, windfall, brush, and litter; the quantity, arrangement, size, species, and decay of such fuels; and the trenching and dirt-smothering chance as related to roots, soil, rocks, and slope conditions.

The following examples of fuel types (Hornby 1936, p. 100) are given in order that the student may have a clearer understanding of Hornby's dual classification system and also to show how variations in the factors he stresses affecting rate of spread and resistance to control bring about changes in the rating of fuel types within the same forest types.

As shown in the excerpt on page 127 from the standard fuel-types classification used in fire-control planning in the northern Rocky Mountain region, when a western white pine forest type, for example, occurs under climatic and vegetation conditions favoring low inflammability of fuels (flats and northeast slopes and dense stands with continuous ground cover) and the condition of the fuels is such as to present no particular difficulty to fire line construction (trees relatively free of moss and few snags) the area is designated as a low-low fuel type (Example 1). When all the above conditions remain constant with the exception of a change in the factors affecting fuel inflammability

(open stands with greater exposure to sun and wind) there is an increase in the potential rate of spread while the resistance to control remains as before. Therefore such an area is classified as a medium-low fuel type (Example 2). With additional adverse variations in climatic, vegetative, and topographic conditions, the rating progressively changes, indicating faster rates of spread and greater resistances to control, until finally a white pine type on an exposed southwest slope in which the mature timber has been injured by previous fire and having dense reproduction interspaced with much windfall material plus continuous decayed broom-topped snags is designated as an extreme-extreme fuel type (Example 7).

Example Number	Fuel Condition	Rate of Spread	Resistance to Control
1	Mature larch-fir, white pine, or lodgepole pine on protected flats or northeast slopes, where windfall is light and not continuous; stand dense enough to shelter fuels on ground. Ground vegetation conspicuously low shrubs throughout. Trees clean and snags few. Tree moss may be moderate	L	L
2	If stand is exposed to almost full sun and wind has moderate access to ground	M	L
3	If windfall and snags are moderate but conspicuous and mixed with thin but continuous grass carpet and stand is exposed to wind and sun	M	M
4	If windfall and snags are moderate to heavy, continuous and intermixed with only scattered trees of the old stand, and reproduction does not fully shade windfalls		
	On protected NE slopes	M	H
5	On exposed SW slopes	H	H
6	If these same mature stands were burned over by light fire, or were heavily bug-killed, resulting in dense reproduction 20–30 years old, not completely shading windfalls and mixed with very heavy accumulation of limby windfalls and continuous rotten, broom-topped, or otherwise inflammable snags 50–75 feet apart		
	On protected NE slopes	H	E
7	On exposed SW slopes	E	E

E = extreme; H = high; M = medium; L = low.

Hornby's fuel-type concept is one of the mileposts in the scientific organization of forest fire control. Its principle has been universally adopted in this country in present-day national forest fire-control plan-

ning (Anonymous 1937*b*, p. 138). However useful as fuel-type maps are to a fire-control organization, the large cost involved in securing the initial basic data plus the recurring cost of keeping such maps up to date have led many to question both the need and the justification of the degree of refinement employed by Hornby in classifying fuel conditions to a point where almost 50 standard fuel types are recognized in one forest region alone. That such refinement is not apparently needed in fire-control planning even in a region having a fire danger equal to, if not greater than, that of the northern Rocky Mountain region and a value of resources at stake far in excess of that region is illustrated by the fact that only six "fire-control zones" are used as basic fuel types in southern California. These fire-control zones are essentially broad botanical life zones, and, as Show et al. (1941, p. 1) state, the "Classification of land into significant fire-control zones is in sharp conflict with the system of classification by fuel types used in most other regions."

Aside from the northern Rocky Mountain region, where the forest areas have been classified into distinct fuel types, a relatively few standard fuel types typical of the area in question are used. These standards in most cases, especially in the East, are basically an adaptation of previously prevailing recognized forest timber types. Thus, in the mountainous eastern national forest region only fourteen standard fuel types are recognized (Jemison 1941), while five suffice in the pine region of southern New Jersey (Little 1945).

Mapping Fuel Types

As pointed out by Hornby (1936, pp. 89–108) fuel mapping is a highly responsible work because the correct planned suppression action depends to no small degree upon its accuracy. He also emphasizes the fact that the best fuel mapper is one who has had considerable experience in suppressing many small fires. Where a large number of standard fuel types are involved it is of material assistance to the fuel-type mappers if pictorial material depicting representative samples of the various fuel types is available for reference. In this connection the northern Rocky Mountain region of the U. S. Forest Service has issued a pocket-size pictorial atlas of fuel types.

The actual mapping of fuel types in the field is done by properly trained and qualified personnel who, from ocular inspection of the area bordering established routes of transportation or inspection from elevated points where close examination is impracticable, sketch in

the boundary lines of the fuel types on standard U.S.G.S. topographic sheets or other available base maps. The fuel conditions of the respective areas delimited as to the rate of spread and the resistance to control are indicated by a suitable mapping legend. The fuels should be rated as they will probably be 5 years after the examination, and 10 acres is the smallest unit to which fuel types are shown on the maps.

In the Lake states national forest region where timber-type maps are checked as to fuel-type conditions, one survey strip through a section has been found sufficient to furnish the basis for fuel-type maps (Anonymous 1937*a*, p. 6211). Matthews (1937) has suggested the use of small plots (milacre squares, 6.6 by 6.6 feet) in rating forest fuels. He states that from one to ten of these plots may be needed per acre, the number depending upon the size of the area being sampled and the uniformity of its fuels. It is highly problematical whether this method with the detail to which Matthews indicates the various fuel conditions are estimated will ever be used except to obtain data for the most intensive analysis of variables affecting fire behavior. Much more to the point from a practical consideration in fuel-type mapping is the recommendation by Lee (1941) of the use of aerial photographs supplemented by field checks much in the same manner as aerial timber surveys are made. He outlines methods of utilizing aerial photographs for both extensive and more intensive fuel-type surveys.

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CHAPTER 11

Presuppression: Fire-Danger Rating

THE NEED FOR FIRE-DANGER RATING

An important presuppression activity is the rating of fire danger and its current measurement.

Within any given forest region the planned activities of a fire-control organization are based on a definite period of calendar dates which include the so-called normal fire season. Yet, in every forest region the greatest portion of the annual loss from fire takes place within a relatively small fraction of the fire season because at such times conditions are particularly favorable for the easy start and rapid spread of fires. The number of fires originating during these exceptionally dangerous periods may not be greater proportionally than during other parts of the fire season. However, the acreage burned over and damages resulting from such fires form the largest percentage of the annual total because of their more rapid spread and greater difficulty of control.

The conditions which make possible the exceptionally dangerous periods during the fire season ordinarily develop suddenly, as for example the occurrence of dry lightning storms. Frequently their intensity is the result of the cumulative effect of a variety of interrelated past events tending to increase forest inflammability such as progressively higher daily air temperature and wind velocity accompanied by lower daily relative humidity. If fires are to be controlled promptly and kept small during such periods, a larger field force is needed than at other times during the field season. The maintenance throughout the entire fire season of an organization sufficiently large to cope with the peak periods of fire danger is financially prohibitive. Nor would this practice make for efficient expenditure of fire-control funds that

should be used commensurate with the degree of existing fire danger. Only on this equitable basis can the availability of sufficient men and adequate facilities be assured at all times during the fire season.

To meet the situation imposed by variations in fire danger, the regular fire-control organization must be strengthened by bringing extra men into the forest for such emergencies or by shifting men from other work. In the East, where man power is usually readily available and where transportation systems are so developed that all parts of the forest can be reached quickly, the increase in the field force may often be accomplished in time to meet the sudden development of dangerous fire conditions. In the West, however, where forested areas are less adequately supplied with the means of transportation and man-power resources, this is less readily achieved.

Regardless of whether men and facilities can or cannot be placed promptly during the variable conditions of the fire season, a reliable means of evaluating current fire danger is necessary if its day-by-day fluctuations are to be known. Such information is essential in the predictions of burning conditions and in setting up the standard of performance required of the field force. Estimates of current fire danger must be expressed in numerical classes having definite meaning and calling for definite action if they are to serve as the justification for releasing large sums of money for suppression on one forest area and withholding expenditures on another area. No standard method of rating fire danger was available prior to the time forest fire research developed methods for measuring the variables involved and devised a mechanism for integrating the net effect of these variables.

THE PRINCIPLES OF FIRE-DANGER MEASUREMENT

In Chapter 6 fire danger was defined and it was pointed out that fire danger is the resultant of both constant and variable factors. Of these two groups of factors, it is the variable ones—all weather elements, fuel moisture content, and variable risks of ignition—that are of chief concern in planning current fire-control action. In the first place, these factors are the primary controls of fuel inflammability which in turn has such a marked influence on the rate of spread of a fire once it gets started. Secondly, they also are of importance to other phases of fire control, such as the effect of variations in atmospheric visibility upon detection.

From the previous discussion of forest fuels it is evident that the

weather conditions are responsible for fluctuations in fuel moisture. Weather is, however, the resultant of many interrelated factors none of which when measured alone can be depended upon to be indicative of the existing fire danger. For instance, periods of high precipitation make forest fires impossible by making fuels so wet they cannot be ignited by ordinary firebrands. There may be thousands of cubic feet of fuel per acre, but unless its moisture content is sufficiently low it cannot be ignited and burned. Between periods of precipitation, however, the effect of weather upon fuel moisture content depends not only upon the amount of the last rain but also upon the type of fuel itself and such other climatic factors as sunshine, temperature, relative humidity, and wind. Under equal conditions, the rate at which moisture is lost by such light-weight fuels as dead grass, hardwood leaves, and pine needles is materially different from the rate at which the more massive fuels like heavier branchwood and logs lose their moisture. Once rain has ceased, the former class of fuel changes quickly in moisture content with changes in weather, while the latter classes, being relatively heavy, do not. The effect of each weather factor upon fuel moisture varies in importance depending upon its association with other factors. Under similarly high air temperatures, a low relative humidity is of greater significance in causing a reduction in fuel moisture than a high relative humidity. Similarly, wind direction that is of such pronounced importance in certain portions of California, Oregon, and Washington is less markedly correlated with changes in fuel moisture in other forest regions. The relative importance of these controls of fuel moisture must be evaluated in estimating current fire danger. A knowledge of them is indispensable when applying weather forecasts to fire-danger estimates in order to arrive at predictions of burning conditions in the immediate future.

The moisture content of fuels is a key fire-danger factor because it is the best single index to forest inflammability. It may be either estimated indirectly or measured directly. Since the weather controls forest fuel moisture, any of the important weather elements can be used to estimate it. By correlating fuel moisture data with various weather elements, indexes of fuel moisture content based on weather elements alone have been devised. The most commonly used are relative humidity alone or in combination with air temperature, evaporation rate, and the interval since last rain. These have been found to be fairly dependable for the light-weight fuels in which moisture changes quickly with variations in weather. Weather measurements

as indicators of fuel moisture content are, however, less satisfactory where the common fuel consists of heavier materials such as thick duff, branchwood, windfalls, and the like. For such fuels, direct measurements of moisture content made with either the duff hygrometer or fuel-moisture-indicator sticks have been found to give the desired degree of exactness. The latter are now preferred because of the relative cost and difficulty of calibrating the duff hygrometer and its relative inaccuracy for moisture contents above 25 per cent.

Two additional factors are usually included in rating fire danger. These are the condition of the vegetation and the season of the year. The condition of the vegetation expressed in terms of its relative greenness or vegetative stages is an important contributor to the intensity of fire danger. When grasses, weeds, and shrubs are green they tend to retard the rate at which fire spreads. When dry or in the cured stage their effect on fire danger is reversed. During the transition stages, in the spring when vegetation is just coming up or in the late summer and early fall when it is curing, the effect on fire danger is intermediate.

Season of the year is an indirect measure of both solar radiation and length of day, two factors having a decided effect on the drying rate of forest fuels and hence upon fire danger. The intensity of solar radiation varies with the calendar reaching its maximum in summer when the sun is at its zenith. In mountainous and hilly country in north latitudes the march of the sun toward and away from its zenith particularly effects the drying rate on north slopes. The length of day affects fire danger in two ways. First, during periods when days are long, forest fuels are exposed to more hours of the sun's heating and drying effects. Second, under the long hours of sunlight during the summer months low fuel moisture conditions tend to be maintained for longer periods, thereby increasing the duration of dangerous fire conditions.

FIRE-DANGER RATING SYSTEMS

To date, three distinctly different methods of rating fire danger have been devised and used extensively. These are based upon the use of:

1. Fire-danger meter method.
2. Cumulative relative humidity method.
3. Canadian fire-danger tables.

Fire-Danger Meter Method

The first systematic method of measuring fire danger into specific classes and associating these with definite steps in fire-control organization was developed in 1933 by Gisborne (1936*b*). On the basis of intensive fire-weather research, studies on going fires, and analysis of fire records, six factors were selected as the most significant variables affecting daily fire danger in the western white pine type of the northern Rocky Mountain region. These were as follows:

1. Wind velocity, the weather factor having the greatest effect on rate of spread of fire.
2. Fuel moisture content (as measured with a duff hygrometer or standard fuel-moisture-indicator stick), the most direct index of fuel inflammability.
3. Relative humidity, the weather factor controlling the moisture content of such finer fuels as tree moss and dead grass when these are extremely dry.
4. Calendar date within fire season, the indirect measure of the stage of growth of vegetation and the number of hours of dangerous burning weather prevailing.
5. Visibility range, the detection factor directly determining the intensity of lookout station manning.
6. Lightning, the principal fire-starting agency in the region.

Various combinations of these fire-danger factors were worked out in such a way that they could be referred to a scale of fire danger having seven classes. This number was selected by Gisborne because it could be associated directly with the seven progressive stages in man-power placement of the regional fire-control plan. In addition it was found that fairly definite characteristics of fire behavior could be ascribed to each of such seven classes of danger. Thus, under fire-danger class 1 (the lowest) no men need be specially detailed to fire control because brush burning and other fires do not spread enough to require trenching. Under fire-danger class 7 (the highest) all available man power and every economically justifiable step should be taken because of explosive fire conditions with fire spreading at rates up to 1500 to 2000 acres per hour on timbered north slopes of even density during afternoon and evening.

The integration of the net effect of any combination of the six fire-danger factors expressed in terms of fire-danger class was accomplished by a pocket-size cardboard slide-rule device, the fire-danger

meter proper. Manipulation of this ingenious device in determining class of fire danger required only two operations. On one side of the meter the correct settings for visibility distance, calendar date, and lightning were made by moving two slides. On the reverse side, fire-danger class according to various combinations of fuel moisture content and wind velocity was shown in addition to the special adjustment for low relative humidity and the usual organization according to class of fire danger.

This method of rating fire danger enabled a fire-control organization for the first time to obtain dependable estimates of current fire danger from its different units which were comparable with each other. Furthermore, upon the receipt of weather forecasts for the territory, the degree of danger at the moment as indicated by the fire-danger meter being known, it was also now possible to estimate on a sound basis the fire danger on the following day and to take action accordingly.

Gisborne's principles of rating fire danger have been used largely in developing similar danger rating schemes in other forest regions so that the fire-danger meter or a comparable device has become the universal means of measuring fire danger on federal, state, and privately protected forest lands in this country.

Following quite closely the pattern of the original, other danger meters based principally on fire research at regional federal forest experiment stations have been perfected for each of the important forest regions. Since the effect of the individual weather elements upon fuel inflammability varies between regions there is necessarily considerable difference with respect to the weather factors used in these danger meters. All of them, however, include wind as a danger factor. Similarly, all use measured fuel moisture content or take this factor into account by amount and number of days since last rain. Integration of the combined factors used in the various meters is done either automatically as the values are applied or by means of a separate simple integration table. The table is employed with the so-called fire-danger board developed in the Pacific Northwest region which has the added public-relations feature of depicting the class of fire danger and the factors concerned by means of a suitable color scheme. There is, however, little uniformity with respect to the number of danger classes used. These range in number from five in the case of the longleaf-slash pine and the Appalachian fire-danger meters to one hundred in the case of the latest model of the northern Rocky Mountain danger meter. Most of these meters have been fully described in the literature, and for a more detailed account of them the

reader is referred to the following: Matthews and Campbell 1939; Bickford and Bruce 1939; Brown and Davis 1939; Curry, Gray, and Funk 1940; and Jemison 1942.

From the above discussion it is apparent that no single rating method based on common factors has been developed and that at present the use of the various danger meters is limited by regional forest boundaries. Likewise some of the early developed meters included factors which have no direct bearing on variable fire danger as now defined. This applies particularly to the use of visibility distance and to lightning. The lack of agreement has been a serious handicap in correlating fire-control work between states and regions by such agencies as the U. S. Forest Service and the National Park Service which handle forest lands in all regions.

During the past decade one of the major developments in fire-danger meters has been centered around the problem of closer agreement as to the universally important fire-danger factors to be measured and the specific type of fire-danger indexes obtained by different combinations of such factors. As Jemison (1944) has pointed out in discussing fire-danger indexes the use of fire-danger ratings becomes most effective when it is known exactly what kind of rating is involved and just how it must be modified to meet every need.

From these efforts there has been evolved the commonly accepted concept that the burning index * is fundamental to every other type of danger rating. All of the fire-danger rating systems now in use by the U. S. Forest Service include a determination of burning index either by first integrating its factors on the danger meter proper before other fire-danger factors are applied (Region 5 danger meter), by means of separate burning-index tables (Region 6 burning-index tables), or from a separate burning-index meter (Region 1 burning-index meter).

Since burning index provides a useable measure of relative inflammability it may be used as a general guide to control measures that should be adopted. When correlated with additional factors, the burning index produces four major types of fire-danger indexes, namely:

1. Preparedness index (burning index plus risk and visibility) that merely shows the urgency of having men and equipment ready. The Region 1 fire-danger meter, model 6, is of this type.

* Burning index is defined as a relative number denoting the combined evaluation of the relative inflammability of forest fuels and the rate of spread of fire in such fuels for specific combinations of fuel moisture content, herbaceous stage, and wind velocity.

2. Rate-of-spread index (burning index plus fuel type and topography) that shows for each combination of conditions the rate of increase in the perimeter of any fire that might start. The Region 1 spread meter is an example (Sutliff 1937).

3. Dispatcher's index (rate-of-spread index plus travel time, resistance to control factors, and personnel factors influencing output of fire-line construction) that indicates the number of men needed for suppressing a fire under given conditions. The dispatcher meters of Sutliff (1937) and Mitchell (1942) follow this principle.

4. Fire-line index (rate-of-spread index plus weather forecast) that, when used on an actual fire, indicates the rate of spread in the future.

Cumulative Relative Humidity Method

The cumulative relative humidity system developed by Shank (1935) for rating fire danger in the Intermountain region of the U. S. Forest Service has been superseded largely by fire-danger meters. However, it still is the outstanding example of utilizing a single easily measured weather factor as an index to forest inflammability. For this reason it is briefly discussed.

Previous attempts to devise a reliable correlation between relative humidity and fire behavior were all based on studies of day-to-day records. Shank's system differs radically from this conventional method. It is founded on the theory that fire behavior is more dependent upon the cumulative effect of relative humidity in the past than upon currently prevailing humidity. Accordingly, the first step is the establishment of a fixed base between relative humidity and initial fire-danger conditions; this is obtained from an analysis of fire records and humidity on the corresponding days. Once this base relative humidity has been determined, algebraic differences between it and current humidity are computed daily. These differences are accumulated algebraically. When the cumulative excesses (plus) and deficiencies (minus) are plotted the resultant curve shows in a striking manner the course of fire-danger intensity. As a guide to administrative fire-control action this curve is used in conjunction with four cumulative relative humidity periods ranging from Period 1 (relatively safe conditions), when cumulative humidities are all in excess, to Period 4 (critical conditions) when cumulative humidities are minus 121 or greater.

The outstanding feature of this system is its simplicity with respect to the basic data required and the maintenance of the daily record.

The principle behind Shank's method, although seemingly sound for the central Idaho region that has a fire season characterized by protracted low relative humidity and scanty precipitation, was found to have definite shortcomings. The most serious of these was a tendency of the curve to lag behind current burning conditions and the fact that the curve still indicated high humidity deficiencies even after the fire season was terminated by favorable weather conditions.

Canadian Fire-Danger Tables

In Canada, from the Rocky Mountains eastward, the rating of fire danger is based upon measurements of certain weather elements applied to a series of fire-danger tables (Beall 1946). The present system is based largely upon the previous work of Wright (1932) who used evaporation rate as an index to fuel moisture content in similar tables. This factor has been eliminated and now only three instruments are essential in measuring the weather elements involved namely, a rain gauge, a wet- and dry-bulb psychrometer, and an anemometer.

The Wright system of showing both fire hazard and fire danger on a single scale is still retained. As used in the Canadian system, the hazard index represents the fuel inflammability conditions in a particular forest or fuel type, while danger index is the average of several types. The latter is actually an average hazard index intended as a guide to general forest inflammability conditions throughout a particular forest region. This scale ranges from index 0, the safest conditions, to index 16, the worst possible conditions. Five zones of hazard and danger indexes are also recognized, from the nil zone (index 0), which calls for special fire-control action only in the event of recent thunderstorms, to the extreme zone (index 13 to 16) for which the greatest possible strength of a protection unit is indicated.

The fire-danger tables consist of a series of four sets of charts as follows:

1. Rainfall and dry weather tables. The former shows the wetting effect of rain upon the surface litter and the latter the effect of temperature, wind, and relative humidity upon fuel moisture.
2. Drought table which evaluates the influence of the moisture content of moss and windfalls upon forest inflammability.
3. Fire-hazard tables for four separate fuel types: pine, cutover softwood slash areas, dry barrens and old burns bearing little or no tree growth, and pure grassland areas.

4. Fire-danger tables separately for eastern Canada generally, the Central Plains region, and the eastern slopes of the Rocky Mountains.

Hazard- and danger-index values are obtained from these tables by first applying current measurements of relative humidity and wind velocity to the dry weather tables or the amount of precipitation to the rainfall tables, as the case may be, to secure what is termed a tracer index. Next, a drought index determined according to the amount of last precipitation is derived from the drought table. The tracer and drought indexes when applied to appropriate fire-danger and fire-hazard tables show the average regional fire danger as well as the individual fire hazard by fuel types within the same region.

Fundamentally the Canadian method is a basic burning-index system since it takes into account only two variables of fire danger, fuel conditions and weather. Although the various tables are more troublesome to use than simple cardboard devices of the fire-danger meters this system has several noteworthy features. In the first place only relatively simple weather measurements are needed, an important consideration where funds do not permit setting up a central agency to handle the work involved in connection with instruments for measuring fuel moisture directly. Secondly, both regional estimates of fire danger and estimates of fire danger separately by fuel types within the region can be secured from the same basic weather data. This feature should be particularly useful on protection units having extensive areas of radically different fuel types yet only one fire-danger station for an entire unit.

FIRE-DANGER STATIONS

The basic data needed in rating fire danger by any of the methods discussed are obtained at special forest meteorological stations known as fire-weather or fire-danger stations. These are commonly maintained at primary lookout stations, ranger and guard stations, and experimental forest headquarters. Such stations are equipped with the instruments required to measure the meteorological and special fire-danger factors employed in the particular fire-danger rating system.

Whenever possible, standard meteorological instruments are used in measuring weather elements (Gisborne 1936*a*). In this connection low-cost but dependable instruments have been devised for measuring precipitation, relative humidity, and wind velocity (Jemison 1942). Fuel moisture content is most commonly measured by fuel-moisture-indicator sticks (Gisborne 1933; Matthews 1935; Jemison 1942). In

the western regions of the United States "triplet" sticks (three ½-inch cylinders of ponderosa pine about 20 inches long and doweled together) are used; in the eastern regions the Appalachian type (three flat slats 18 inches long of basswood Venetian blind stock) is employed. To determine the moisture content of these sticks they are weighed on either an ordinary balance or a special fuel-moisture scale (Byram 1940).

In addition, most fire-danger stations have an instrument shelter for housing such equipment as the fan psychrometer, the scale, the buzzer and batteries of the anemometer, and rain-gauge stick.

The number of fire-danger stations required to sample adequately the major differences in weather conditions and fuel moisture depends primarily upon topography. Morris (1940) has shown that, principally as the result of topography, a relatively large number of stations are needed in the Northwest to attain an accuracy even within 5 miles per hour in mean daily maximum wind velocity. He also found this to be true with respect to attaining an accuracy of mean daily minimum fuel moisture within 2.5 per cent. In contrast, for the uniformly level Southeast, Knorr (1942) indicates that a small number of stations are needed since no significant difference among stations was found regarding fuel moisture content. He points out, however, that even in the flat longleaf pine region there is sufficient variation in wind velocity to warrant running a series of wind velocities on tentative sites in order to determine which one is representative of worse-than-average wind velocities before establishing a permanent fire-danger station. In the mountains of the East, Jemison (1942) believes that one station per 150,000 acres is enough to start with, whereas in certain parts of eastern and central Canada it has been found that if no point in an area is more than 25 miles from a fire-danger station very reliable results are obtained (Beall 1946).

In establishing a fire-danger station due care is taken to select a site the surrounding vegetation and ground cover of which are typical of the general area. In order that measurements of fuel moisture and weather conditions, particularly wind velocity, will be truly representative of the immediate surroundings, in mountainous country consideration must be given to the effect of altitude and aspect on fire danger. In this connection the studies made by Hayes (1944) are particularly instructive. For northern Idaho conditions, he concludes that single measurements of fuel moisture and wind velocity taken daily at noon at either a valley-bottom or a south-slope station are adequate for rating fire danger.

Since fire-control planning commonly contemplates a field organization capable of suppressing all fires except those that might start in the worst fuels under the most severe burning conditions, the proper exposure of instruments at fire-danger stations is extremely important. While uniform exposure of fuel-moisture-indicator sticks is highly desirable, measurements of fuel moisture made in full sun are avoided because they represent the extreme of danger. When the sticks are fully exposed in the interest of comparability between stations, they are sometimes covered by wire screens to simulate the degree of shade produced by the forest canopy. This is the uniform practice employed at the fire-danger stations in the coniferous forests of the northern Rocky Mountain region (Gisborne 1936*a*). In hardwood forests similar comparability is largely taken care of by the essentially full exposure of the area to the sun during the leafless season and the complete shade during the summer. Standards of exposure are usually adhered to in placing the instruments measuring wind velocity and precipitation. Anemometers are supported at a standard 8-foot level so placed as to receive winds from every direction or at least the prevailing daytime direction. Rain gauges are located in openings in the forest or in nearby clearings where a 45° angle from the top of the gauge clears the nearest obstacle. When measured, air temperature and relative humidity are taken within the instrument shelter proper which has its door facing toward the north to prevent the sun's rays from falling upon the thermometers of the fan psychrometer.

From one to three daily observations at stated hours (commonly 8 A.M., 2 P.M., and 5 P.M. local time) are recorded at fire-danger stations. When only one daily observation is made the preferable period is between 2 P.M. and 5 P.M. This normally coincides with the lowest daily fuel moisture value. In applying the recorded observations of fuel moisture and wind velocities to fire-danger meters and similar devices for estimating the class of fire danger a standard practice at stations making three daily observations is to use the lowest fuel moisture and the average of the two afternoon wind velocities for the day. After the daily rating of fire danger has been computed, it is transmitted along with the other recorded observations to the dispatcher or ranger charged with assembling, summarizing, and keeping an up-to-date record of fire danger on his protection unit. The keeping of such a record is important and should not be neglected since the data have permanent value.

APPLICATION IN FIRE-CONTROL ACTIVITIES

The original purpose of the various systems of measuring fire danger was largely directed toward providing a dependable scale of current forest inflammability which could be used as a guide to the possible fire-suppression load. Experience with such fire-danger ratings has shown, however, that they are of help in all phases of fire-control work. Jemison (1942) and Beall (1946) have listed these in detail. The most important of these uses are summarized below.

Application in Prevention

1. As a basis of warnings issued as press releases and radio bulletins directed toward educating the public to care with fire during periods of high fire danger.
2. As a guide in enforcing regulatory prevention measures such as the closure and reopening of forest areas to public travel and industrial operations, restrictions on smoking, and the issuing and cancellation of brush-burning and camp-fire permits.
3. As a means of testing the effectiveness of fire prevention programs which must take into account the variations in fire danger existing during the campaign.

Application in Presuppression

1. As an index to unseasonable periods of fire danger thereby enabling the fire-control organization to be prepared when such off-season emergencies occur.
2. As a measure in regulating the size of the presuppression organization as weather and other temporary aspects of fire-danger change during the normal fire season.
3. As a basis in making comparisons of the severity of fire seasons for any one fire-control unit, in judging efficiency between different protection units, and in determining man-power and financial needs between several fire-control units.
4. As an aid to new men and also the more experienced in gaining a rapid knowledge of the particular fire job.

Application in Suppression

1. As a guide to the dispatching to fires of the number of men commensurate with the intensity of fire danger.
2. As an aid, when used in conjunction with weather forecasts, to fire bosses in determining the best methods of controlling a fire, the additional man power required, and the reduction in man power as fire danger decreases.
3. As an indication of fire intensity and hence severity of damage to be expected, fire-danger ratings are of value in making damage appraisals.

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CHAPTER 12

Presuppression: Fire-Control Policy and Objectives

FIRE PLANS

All fire-control activities require planning as the basis for effective accomplishment. Proper balance and coordination must be provided for between all the various fire-control activities. The problem as a whole must be visualized before the emphasis to be given each detail can be correctly evaluated. As the name implies, a fire plan is simply a proposed method of action against fires. It should be drawn up by the most competent man who is familiar with the unit for which the plan is made. In some cases there may be no written transcript of the fire plan which is in effect. Such a situation may be workable for a small tract but becomes less and less desirable as the size of the unit protected increases. Fire plans are ordinarily subject to revision each year, although many activities such as construction of the transportation and communication systems and the network of lookout stations may be planned for several years ahead.

The basis for a fire plan is found in the fire history of the property. That portion of the fire history of a tract which concerns the immediate past (for example, the past 10 years) is of the greatest value as the foundation for a fire plan. Earlier happenings and conditions, particularly if authenticated by records, may prove instructive in furnishing comparisons. All records of the past (recent or ancient), when used as aids in planning for protection in the immediate future, must be carefully appraised in the light of existing conditions and tendencies, for the past is not always an infallible index of the future. Fire history is recorded mainly in the form of forest fire statistics giving the num-

ber, causes, locations, time of occurrence, character, damage, and size together with records of elapsed time (from origin to time of attack), and methods and costs of fighting. Records of weather, fire danger, physical development of the forest, economic and social conditions of the region, and status of the fire-control system are essential facts assisting in interpretation of the fire history.

The investigation of fire causes together with the seasonal and regional distribution of fires is particularly enlightening. This logically includes a careful study of the local residents and the users of the forest to learn their habits in the forest and to appraise them as potential sources of fires.

Since the fire history is the basis for planning fire control, provision should be made for continuing and constantly improving the gathering of statistics. The importance of accurate, detailed, complete reports on individual fires can scarcely be overemphasized. Such reports form the basis for the fire history of a forest and for fire-control planning. The points to be covered in compiling a full report on a forest fire are listed and well discussed in the instructions issued by the U. S. Forest Service for the preparation of their Form 929, Individual Fire Report (Anonymous 1942).

Forest fire statistics should be kept separately for each forest-protection unit because of the radical differences in the fire situation that may exist in neighboring units. Time should be spent each year in reviewing the fire records of the preceding year. One of the most valuable uses of this material is to study critically the record of each individual bad fire, endeavoring to determine the specific errors or omissions in prevention, presuppression, and suppression that were accountable for the size and destructiveness of the fire. Fire statistics are the chief source of information for determining the hour control needed for the various forest or fuel types. In fact, without adequate statistical data it is impossible to obtain a sound basis for hour-control standards.

In preparing a fire plan all available data concerning the abovementioned subjects should be assembled and analyzed. Most of the material can be shown and studied to best advantage in the form of maps, charts, and tables. As a result of this analytical study, tempered with sound judgment, the plan of action is formulated and elaborated in all necessary detail. The amount of detail justified depends upon the importance of the fire-control problem on the particular forest involved.

Fire plans should be made separately for each area which functions as an administrative unit in fire control. If the forest property is large, several administrative units each with its own individual fire plan may comprise a larger unit with a general fire plan or policy of fire control emphasizing the broader features of fire control. The national forests with several ranger districts (each having a fire plan), making up one national forest containing about 1,000,000 to 2,000,000 acres, and several national forests joined together in one national forest region, covering one or more states, furnish an example of this system.

An outstanding example of a fire plan for a region is the one made by Hornby (1936) for the northern Rocky Mountain region. Another example is the report of Show et al. (1941) entitled "A planning basis for adequate fire control on the southern California national forests." Southern California is a region having both an exceptionally high fire danger and a tremendous value of resources at stake (watershed protection). Intensive fire control is imperative. The methods and approaches to the problem developed in these reports should be studied by those interested in fire-control planning.

Finally, the numerous national forests over the whole country all work under the same general policy of fire control.

In states where a large share of the forest land is owned in small holdings it is frequently too costly to protect each holding as a separate unit with its own fire plan. Here the state must step in and provide a state-wide organization and policy for fire control which the small owners individually cannot afford. In most instances the state finds it more effective to divide the total area into districts each containing several hundred thousand acres.

Another way of overcoming the difficulties which small forest landowners have in planning for fire control is through the organization of cooperative forest fire protection associations. Landowners within a given region may for fire-control purposes throw their lands together, levy an annual assessment on the basis of acreage, and organize fire control for the entire area. In most cases these associations receive help in one form or another from the state forestry departments toward strengthening the protection.

One difficulty often encountered by these associations is that some forest landowners within the region protected refuse to join, and yet the location of these properties with reference to the lands of the members forces the association members for their own safety to protect the lands of the nonmembers. This should be remedied (as already has been

done in some states) by making it compulsory for the private owner to protect his own lands or pay the state for so doing.

Tracts on which logging on a large scale is in progress during the fire season usually have a high fire risk and hazard. On such areas special planning to cope with the situation is needed. The points which should be covered in a fire plan for a logging operation are suggested in the *Pocket Manual on Forest Laws and Practice for the Douglas Fir Region* (Anonymous 1941), and in *Prevention of fire in logging operations* (Joy et al. 1942).

What might be termed the master plan for state and private forest lands in the United States is the line of action built up as a result of the Clarke-McNary law in 1924. Under this law the federal government was authorized to assist in the protection of private lands. The U. S. Forest Service, which had already demonstrated its ability to function effectively in controlling fire on the national forests, was given charge of applying the Clarke-McNary law. The individual states were to administer the law within their territory. The money spent in a given state by the federal government could not exceed the sum spent by private owners and the state. In other words the federal government could pay up to half the total costs while the state and private interests divided the balance between them. The passage of the Clarke-McNary law was a formal step in fire control, strengthening and standardizing the fire-control activities of the state and private owners. As yet the appropriations made by the federal government under this law have not been large enough to meet the need.

FIRE-CONTROL POLICY

Fire-control planners, of whatever grade they may be, require an objective or goal at which to shoot. The objective in general terms is to control forest fires. This does not imply entire exclusion of fire (Beichler 1940), but does imply that fire be controlled and its use properly governed. Complete exclusion of fire from the forest as a practical measure is impossible, even if it were advisable, and should not be considered the objective in fire control.

If complete exclusion of fire from the forest is not the objective, what should it be? How much money can justifiably be spent on fire control and how the money available should be allocated to the different units in the organization are constantly recurring questions.

Sparhawk (1925) carried on a study to find a scientific method for determining first how much money the federal government was justified

in spending for fire protection on the national forests and second a basis for distributing funds to different units. The inadequacy of statistical data available at that time prevented satisfactory solution of the problem.

When fire control is first undertaken on any area it is logical to assume that at least such an amount may be spent on fire control (plus losses in spite of fire control) as does not exceed the present total of fire suppression costs plus fire losses. Under this plan the cost plus damage will be at least no greater with protection than before protection and the forest will be kept in better condition. Experience has proved, and the fact is now generally accepted, that, by increasing the amount spent for fire prevention and for presuppression, and adding the suppression costs and fire damage, the total will be less than the sum of the large suppression costs and damage consequent upon the numerous and large fires resulting through failure to develop adequately fire prevention measures and presuppression activities.

Furthermore forest production will be stimulated by spending funds in preventive measures and presuppression activities instead of the alternative course of allowing an equal or larger value to burn up. One practical difficulty in applying this principle arises because the money value of fire damage is exceedingly hard to determine * because present injuries to trees result in future losses of unknown extent and so much of the injury is to forest growth too small to have any present marketable value.

If expenditures for prevention and presuppression are constantly increased there doubtless will come a time under the law of diminishing returns when decreases in costs plus danger cease to be effected. This point has been reached by few if any fire-control organizations. When it is reached, the acreage burned over and consequent damage may be so small as to justify no further increase in expenditures. On the other

* This difficulty has been partly overcome by using all available forest fire statistics to prepare tables of arbitrarily fixed values for damage to stands of different types, age classes, and conditions. These arbitrarily assigned values serve well from the administrative standpoint in furnishing a uniform method of appraising damage and thereby securing good comparable results over all the territory covered. Damage appraisals are also needed for the purpose of settling claims for loss sustained in individual fires. Here the expensive process of examining the burned-over area, making an inventory of the damage, and appraising this damage in terms of its present financial value must be undertaken. Except where values of merchantable timber before and after the fire are concerned such estimates for the damage on the same fire will vary widely with the estimator and depend for their accuracy upon his common sense and experience. So many

hand, it may be found advisable to reduce the damage still further by additional expenditures for prevention and presuppression. While the necessary experience is lacking, it is anticipated that, as the number of fires and their average size are decreased, a point will be reached beyond which it becomes disproportionately expensive further to reduce number and size of fires. However, larger expenditures than those made today (up to some as yet undetermined point) for prevention and presuppression activities are justified as tending to reduce suppression costs and damage.

The earlier fire-control policy of the U. S. Forest Service, applied on the national forests (Loveridge 1944), called for holding total costs of prevention, presuppression, and suppression plus the value of the damage down to a minimum. The trouble with this policy was that there was no definite knowledge as to the amount of damage. Damage was usually figured altogether too low, and particularly where intangible values were at stake the tendency was to use small amounts of money on prevention and presuppression work. This resulted frequently in very large costs for suppression. The policy might be termed a "let-burn" policy. Oftentimes low-value stands were allowed to burn over particularly when they were in the back country and relatively inaccessible. This policy did not produce very disastrous results, except in the 1910 fires, so long as the wet-weather cycle continued, but by 1917 the dry phase of the weather cycle became evident and this dry phase continued for more than 20 years. Frequently disastrous fires occurred. The old policy usually allowed only small crews for the fires that occurred in relatively inaccessible country. If such fires could not be put out in this way they were herded toward low-value country and allowed to burn until fall rains came and put out the fires. Even though this policy was followed tremendous areas were

factors of unknown value enter into such appraisals that their usefulness for estimating damage for fire-control purposes does not justify the time spent in preparing them. Hence the method of arbitrarily assigning fixed values for different classes of damages is preferable in dealing with fire-control costs.

Noteworthy efforts are being made to increase the reliability of such arbitrarily fixed damage value data by intensive fire damage studies which not only evaluate damage in terms of outright killing but also estimate subsequent losses due to delayed mortality as well as losses occurring as the result of fire-scarred trees being attacked by insects and decay-causing organisms. An interesting and valuable innovation which should lead to more accurate damage appraisals by these latest forest fire research efforts is the evaluation of intensity of burning conditions at the time of fire occurrence by the use of local measured fire-danger ratings (Stickel, undated; Mitchell 1938; Barrett, Jemison, and Keetch 1941).

burned over and costs of suppression were very high. This can be seen from the following data which are only for the western national forests in Loveridge's article:

	Wet-Cycle Years 1911–1916 Incl.	Dry-Cycle Years 1919, 1924, 1926, 1929, 1931, 1934
Number of "bad fire years"	0	6
Average acreage burned annually	352,921	980,214
Average annual special suppression expenditures	$224,843	$2,626,240

Bad blow-ups became frequent, and it was soon evident that something had to be done to strengthen the preparedness features of the program.

About this time Show and Kotok (1930) had brought out the relation which existed between the percentage of Class C fires and the total area burned. They stressed the importance of speed of control and predicted that, if all fires were strongly and promptly attacked, the results as a whole would be much better. This idea was finally tried out in the Southwestern region, with the following results:

	Under Previous Policy 1921–1925	Under Tight Control Policy 1926–1930
Average acreage burned annually	18,146	6,290
Average annual special suppression costs	$57,814	$55,125

The good results obtained in the Southwestern region led the U. S. Forest Service to authorize a much more liberal use of emergency funds for prevention and presuppression activities. This was particularly true in the western white pine region.

However, although this was started in 1926 no decided change in the suppression policy was made until after the bad year of 1934. Then at a winter meeting in the early part of 1935 the policy was thoroughly gone over and changed. The fact was recognized that inaccessibility and low value were relative terms which changed with the passage of time. It was realized that intangible forest values had not been fully appreciated and that fires in low-value country frequently spread over into stands of exceedingly high value. That ultimate cost of suppressing one large fire is often greater than the cost of suppressing a multitude of small ones also became apparent. As a result the let-burn policy was given up and it was decided to attack all fires no matter where they were located with fast, energetic fire-suppression methods.

The effort should be made to control the fire within the first work-period; if this failed, then within the next work-period, and so on (a fire suppression work-period begins at 10 A.M. and runs for 24 hours). The policy was put into force in 1935 with excellent results of which the following figures for the western national forest regions are a sample:

	1926–1934	1935–1943
Average acreage burned annually	455,350	141,975
	(0.1 per cent of the area under protection)	
Average annual special suppression costs	$1,860,026	$1,954,401

Furthermore, since the policy went into effect not a single blow-up fire of long duration had occurred (1935–1943) in the national forests of the West.

The 1935 fire-control policy was established by a circular letter of The Forester, dated May 7, 1935, and is here quoted from *Journal of Forestry* 42, pages 552–553:

> The approved protection policy on the national forests calls for fast, energetic and thorough suppression of all fires in all locations, during possibly dangerous fire weather.
>
> When immediate control is not thus attained, the policy then calls for prompt calculating of the problems of the existing situation and probabilities of spread, and organizing to control every such fire within the first work period. Failing in this effort the attack each succeeding day will be planned and executed with the aim, without reservation, of obtaining control before ten o'clock the next morning.
>
> In order to bring out the policy in sharp relief for discussion by the Conference all written interpretative material was stripped from it. However, I believe it is now time for Operation to issue such instructions as may seem necessary to have the policy put into full effect during the coming fire season. These will be sent you within the next few days.
>
> I am confident that the sum total of costs plus losses of all classes will be lower in the long run under this policy than they have been under comparable conditions heretofore. To this end, I am adding the following notes for consideration in placing it into effect:
>
> It may not be clear from the wording of the policy but it is obvious, nevertheless, that the objective sought also projects that policy into presuppression since only by strengthening the presuppression forces in some quarters can the action contemplated be realized. This may call for increasing the standard of detection; plugging holes with additional fireman where so-called fireman or smokechaser travel time is known to be longer than limits of safety; advanced placement of trained fire suppression crews

to be held at carefully selected travel time limit centers. After full use of CCC, PWA, improvement and similar available man power, these additional presuppression sources likely can be provided in the main only by drawing upon FF. To the extent that carefully thought out plans make this necessary, you are authorized to draw upon funds from that source to enable the building up of the presuppression forces to required strength.

Subject to the action required to meet the above quoted policy, expenditures for preparedness and suppression will be held to the absolute minimum, and will vary with the total of the tangible and intangible values endangered; being higher, if necessary, where values are high than in areas where values are low. In lower value country this may call for dropping back to more easily held lines no great distance from the fire front and from these lines taking definite and prompt action to extinguish the fire. In such country lower expenditures will also be expected for firebreaks and other types of improvements, than would be justified were higher values involved.

No fixed rule can be given to meet every situation; the spirit implied in the policy itself will determine the action to be taken in doubtful situations.

Another illustration of the saving realized through carefully planned and efficiently organized fire control is furnished by Gisborne (1940). He compares 5,000,000 acres in the Kaniksu and Kootenai National Forests with a similar area just north across the Canadian line. The two national forests had 521 lightning fires between July 12 and 21, 1939, and all were put out in not over 3 to 4 days after origin. Canada had 185 fires reported and some were still burning on September 1. The national forests in question had 214 men including 90 lookouts on duty July 12, while Canada had only 47 trained men not so well distributed.

The Kaniksu and Kootenai spent $197,000 in suppression and had 5826 acres burned over with a damage of $1.75 per acre, a total of $10,000. Canada had 220,000 acres burned over by 12 fires still burning on August 20 with damages estimated at the same rate ($1.75 per acre). The loss amounted to $385,000 plus agricultural and property damages of at least $30,000 more. The Canadians spent $49,000 in fighting these fires, making a grand total of at least $480,000. No recreation or watershed damages are included.

Fire-control costs in the early stages of forestry may form a substantial part of the cost of growing timber, and the advantage to be gained by any increase in such costs must be carefully appraised. In this connection consideration must be given not only to the tangible value of the timber but also to the intangible value of the forest cover which though difficult to express in dollars and cents is nevertheless of importance.

Forestry and fire control are still in the early stages of development. Old customs must be changed, new viewpoints introduced, and organization for production and protection planned and put to work. For the next few decades the costs of fire control are likely to be more burdensome than later on even though total amounts spent may be greater then. Some of the expenses, such as those for the reduction of hazards, will be eliminated or greatly lessened when the present virgin stands and extensive areas of cutover lands are replaced by thrifty, fully stocked second growth. The business development of the property will result in having a larger and better-trained personnel permanently employed in the forest with a relatively small part of their cost chargeable to fire control. More intensive development of the transportation system (primarily for other purposes rather than for fire control and thus not chargeable to the latter), will permit quicker access to fires and hence lower suppression costs and acreage burned. Fire prevention efforts steadily applied over a period of years may finally result in a more conservative public sentiment and a reduction in the risk of man-caused fires. The forest itself because of its denser stocking of trees and lesser amounts of undergrowth may be less inflammable and cheaper to protect.

OBJECTIVES

The foregoing paragraphs have indicated the advisability of and justification for increasing the intensity of fire-control activities but have not answered the question as to what is adequate fire protection and by what standard such protection should be measured. The phrase adequate fire protection used in the Clarke-McNary law and elsewhere, as a criterion of the protection which should be provided, is subject to various interpretations, yet in all cases fire protection to be adequate must, without unreasonable cost, hold damage from fire at a low enough figure to insure accomplishment of the purposes for which the forest is maintained. Adequate protection is defined (Anonymous 1930) as "that which results in the minimum total of damage, i.e., cost of protection, plus damage, with indirect losses, reductions in value to the public, as by the burning of watersheds, etc., included." This is theoretically sound but nevertheless intangible, as the minimum total can be known only after decades of practice.

Since it is impossible under present conditions to determine tangible and intangible fire damage accurately, the percentage which the area actually burned over forms of the total area protected has been taken as a standard. In applying this percentage as a standard to measure

adequate fire protection, an arbitrary percentage of "allowable burn" is set up for the territory in question. In deciding upon a figure of allowable burn for a given area the criterion used is the maximum amount of injury that the forest can endure without serious interference with the purposes of management. If the area actually burned over annually equals or is less than the allowable burn, protection is said to be adequate; if higher than the allowable burn, the situation is not satisfactory. Allowable burn makes an excellent standard not only because it is a good gauge of the degree of protection but also because it is quickly computed and makes comparisons easy between different areas.

At first the percentage of allowable burn was fixed in an arbitrary manner for each region considered and was customarily set somewhat lower than was at that moment being obtained as a result of existing protection efforts but yet within the possibility of attainment. In other words the standard was set up as a goal for the organization to reach. Presumably when this goal was reached a new and more exacting standard of allowable burn would be set up. Since a wide variation in forest, climatic, population, and other conditions affecting fire danger as well as different degrees of advancement in fire control exist throughout the country not all standards of allowable burn could be set at the same figure. For example, in the western white pine region Koch and Cunningham (1927, p. 12) suggested an allowable burn of 0.25 per cent; in the Lake states, Zon (1928) considered that 0.5 per cent represented highly effective fire protection, because of the fact that in the Lake states during the decade 1916–1925 approximately 2 per cent of the area under protection was annually burned over.

Standards of allowable burn set in this way are likely to be overinfluenced by the existing efficiency of fire control as expressed in the actual percentage of burned areas and underinfluenced by the basic fire danger arising primarily from forest and climatic conditions. Show et al. (1941, p. 36) as a result of careful analysis concluded that in the national forests of southern California "an absolute maximum fire of not over 2000 acres should be the goal, that with expected increased efficiency this corresponds to, or will be associated with a general protection level allowing not over 0.15 of 1 per cent average annual burn on the entire national forest protected area."

In order to obtain a more logical basis for setting these allowable-burn standards than had at first been employed, the U. S. Forest Service worked up a set of comparable, allowable-burn percentages for each of

the more important forest types (Kotok, Kelley, and Evans 1933, pp. 1397–1398). Pines and spruce were considered the types most seriously damaged by fire and were arbitrarily given allowable-burn standards of 0.1 per cent as a starting point for rating the other types. The figures are shown in the next table. In deciding upon the percentages, four points were considered as follows: damage to timber and other forest values, damage to the productivity of the land, difficulty of reestablishing a forest after fire, and effect of fire on difficulty of future protection.

From the standards for the individual types an average value for each tract or region can be worked out and the objective for that area indicated. Objectives thus secured for broad regions and ownership classes are shown in the table on page 158 together with the ratio of actual burn to allowable burn. From these figures it is plainly seen that actual performance at that time (1933) was far below the standards set for adequate protection.

INDEXES OF EFFECTIVE FIRE CONTROL FOR VARIOUS FOREST TYPES
(Taken from *A National Plan for American Forestry*, p. 1399)

Type	Annual Allowable Burn, Per Cent
White pine	0.1
Spruce	0.1
Douglas-fir	0.2–0.3
Larch-fir	0.25
Larch-fir-white pine	0.15
True fir	0.2–0.3
Ponderosa pine	0.3
Mixed conifers (Calif.)	0.3
Lodgepole pine	1
Jack pine	0.5
Norway pine	0.3
Shortleaf pine	1
Loblolly pine	1
Slash pine	0.7
Sand pine	1
Longleaf pine	3
Northern hardwood	0.2
Appalachian hardwood	0.5
Bottomland hardwood	0.2
Oklahoma hardwood	1
Aspen	0.7
Noncommercial forests	2
Brush and nontimbered	2.5
Watersheds	0.4–2.5
Recreation values	0 –0.5

When an attempt is made to attain the allowable-burn objective in a given forest type the factor which immediately stands out as critical is speed of attack. Fires must be reached quickly or the area burned mounts up unduly. The time within which fires must be reached in each type, in order to attain the allowable-burn objective, should be determined and then arrangements made for an organization which will reach the fires within the times designated. In other words, the proper hour control must be learned and then put into effect. The study of hour control was mentioned on page 91 as part of presuppression activity, but its importance in securing adequate protection should be emphasized here.

Objectives in Fire Control on National Forest and State and Private Forest Land, by Regions

(Taken from *A National Plan for American Forestry*, pp. 1399–1400)

Region	State and Private Areas	National Forest Areas	Ratio of Actual Annual Burn to Allowable Burn (Average 1926–30) [1]	
	Allowable Burn, Per Cent	Allowable Burn, Per Cent	Outside National Forests	Within National Forests
New England	0.16	0.13	1.84	0.015
Middle Atlantic	0.35	0.16	2.97	3.78
Lake	0.36	0.43	2.70 [2]	0.85
Central	0.59	0.50	5.36	1.03
South	1.34	0.90	14.19	1.02
Pacific Coast	0.49	0.27	4.96	2.78
North Rocky Mountain	1.05	0.56	0.99	0.87
South Rocky Mountain	0.41	0.49	0.56	0.70
Continental United States	0.88	0.44	11.00	1.07

[1] A ratio of 1 or less indicates that objective has been reached.
[2] Data incomplete for certain areas in Wisconsin and Minnesota.

As yet information on the required hour control for most forest types is lacking. An analysis of the subject was made by Show and Kotok (1930) for the forest types in the California pine region. In 1936 Hornby made an intensive study of the time within which fires in the

fuel types of the northern Rocky Mountain region must be reached to obtain the desired objectives, and his plan for fire control is governed fundamentally by the time element.

In addition to allowable-burn objectives as listed on page 157 which are set up for individual forest types, it is advantageous from the administrative standpoint to establish comparable fire-danger ratings for the different administrative units, thereby facilitating a fair allocation of fire-protection funds and furnishing a basis for judging accomplishment. Such a rating may be based on the periodic and seasonal changes in fire danger as shown by the fire-danger meter and thus indicate the temporary placement of protection forces, or it may consider the more permanent aspects of fire danger and assign a rating to a given area which will hold for one or more years.

Whether a relatively permanent or a temporary fire-danger rating should be employed will depend on the purpose for which it is to be used. For example, Hornby (1936, p. 85) gives each national forest in the western white pine region a relative fire-danger rating on the basis of the combined effect of fuels, probable damage from fire, and frequency of fire occurrence. This is a fire-danger rating of the permanent type. For the same national forests and for individual portions of each forest day-by-day the total seasonal ratings may be compiled by use of the fire-danger meter which rates principally the weather elements and other temporary factors of fire danger, thus indicating current variability.

The daily and seasonal ratings so obtained furnish a basis for daily changes in fire-control operations, and the seasonal fire-danger ratings for all units on a comparable basis are invaluable for appraising efficiency and justifying allocation of funds.

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CHAPTER 13

Fire Suppression

The last stage of fire control is putting out the fires which originate either from unpreventable causes or because prevention is not perfect. When fires start, the effectiveness of the presuppression activities is tested.

On discovery of a fire, the firefighters are notified and hasten to the fire. As previously stated, fires should be reached while still small; otherwise suppression costs and damage mount rapidly. The principle is the same as with building fires; speed of attack is fundamental in fire suppression. Presuppression activities have been directed among other things toward reducing to an acceptable minimum the time which must elapse after discovery of the fire until the fire is attacked.

NUMBER OF FIREFIGHTERS NEEDED

The question as to how many men will be needed to control the fire arises as soon as the fire is discovered. Theoretically the number sent should depend upon the fire danger (as expressed in part by the burning-index class), which in itself is the summation of many climatic, topographic, vegetative, and man-made factors. The exact number of men needed for an individual fire may vary widely from day to day and from place to place with the burning index. The factors influenced by topography, vegetation, and man are more likely to remain constant for the whole or part of a fire season than those of climatic origin.

In regions particularly with excellent transportation systems and fairly fast fire spread, such as Connecticut, a small crew-unit of 2 to 5 men is ordinarily sent to every fire with the idea of controlling it quickly and getting back to headquarters. Should one crew unit prove

unable to control the fire quickly other units are promptly sent. Undoubtedly for a short time at many fires there may be more men than are needed. Where men are plentiful and transportation is good, the important factor of safety secured by having a few extra men is economy in the long run.

In regions where most of the fires are of the slow-burning type, it may prove most economical to send a single man to the fire and later to send others if necessary.

The smokechaser used widely in western forests provides one-man initial attack. Usually the man with the shortest travel time to the fire is sent in. He may be followed shortly by additional men if in the judgment of the dispatching authority such action is needed. Suppressing fires with a single smokechaser for initial attack works best in country where fires have a relatively slow spread and suppression is mainly by hand tools.

In U. S. Forest Service practice the number of men needed to suppress fires under each burning-index class and other conditions affecting fire danger is estimated in advance of the fire season and may be listed in tables. The method is based in principle upon the rate of fire spread and resistance to control under varying burning conditions together with the length of fire perimeter which can be controlled by one man in a given time. The common expression for this latter point is length of held fire line, by which is meant the length of the fire perimeter on which the fire is actually controlled. It is one of the best measures of the efficiency of firefighters when working under comparable conditions.

Tables may be made up indicating the number of men that should be sent out to fires under a great variety of conditions. Since the problem logically divides into the initial attack, the need for light reinforcements, and the need for heavy reinforcements, these tables may be further separated to indicate the number of men to be sent out on initial attack and as reinforcement when required.

As an example, Hornby (1936, pp. 60–67) has determined for the northern Rocky Mountain region, on the basis of past fire history, the number of men that should be sent on initial attack, as light reinforcements, and as heavy reinforcements. On the basis of fuel resistance to control and burning conditions, the number of men needed on initial attack ranges from 1 to 20. Crews of 5 to 50 men are sent in as light reinforcements when needed and are drawn from the smaller communities. Heavy reinforcements are crews of 100 men or more sent in by autobus from larger centers of population. Hornby's graphs indicate

that approximately 6 per cent of the fires, those spreading better than 18 chains of perimeter increase per hour, may require heavy reinforcements. Light reinforcements may be needed for the 16 per cent of the fires spreading faster than 8 chains per hour while about 84 per cent, namely, the slow-spreading fires, can be handled by the initial attack crew.

Stephenson (1936) dealing with forest conditions in Mississippi based decisions on number of men sent to fires upon the changes in rate of spread and size of fires caused by fuel type, wind velocity, relative humidity, hour control, and time of day at which the fire occurs. His dispatching tables show man power required for combinations of any of these conditions.

For Lake states conditions Mitchell (1942) developed a fire-dispatching guide for determining number of men to send to fires using as basic factors "(1) danger or burning conditions as indicated by the Lake states fire-danger meter, (2) wind velocity, (3) travel time, and (4) fuel-type class based on rate of spread and resistance to control."

On the national forests the objective of controlling the fire within the first work-period, that is, before 10 A.M. the beginning of the next midday burning period following the attack on the fire, should guide the dispatcher in deciding on number of men to send in as initial attack and as reinforcements.

In applying the U. S. Forest Service policy of attacking each fire with the objective of controlling it within the first work-period, an estimate must be made and recorded as to the number of men required to suppress the fire. This requires:

1. An estimate of the number of chains of perimeter at end of first work-period.
2. An estimate of the length of held line which can be constructed per man per hour.
3. Division of (1) by (2) to give the number of man-hours of work needed to control the fire in the first work-period.
4. An estimate of the number of hours the crew will have available to work in the first work-period.
5. Division of (3) by (4) to give the number of men needed for fire line construction to suppress the fire.

The method of suppression which will be used on the fire may determine the number of men sent on initial attack. For example, the number of men needed to work effectively with a unit of mechanized equipment is more or less fixed and determines the size of crew to go with the outfit.

METHODS OF FIREFIGHTING

Firefighting is an art which is widely practiced and applied in differing detail to fit local conditions. The principles of firefighting are the same over the entire country, notwithstanding the range in forest, climatic, and economic conditions. As Gisborne (1948) points out in discussing the fundamentals of fire behavior, fire is a chemical process involving three essentials: fuel, heat, and oxygen. In fighting fire, success is attained when one or more of these three essentials is prevented from entering the chain of events that takes place when fires ignite, burn, and spread.

The term "put out" or "extinguish" a forest fire is frequently employed, but as a matter of fact only fires of the smaller sizes are entirely extinguished. To extinguish a fire requires that on all portions of the burned-over area the flames be put out and the embers be cooled down to temperatures below the combustion point. Such treatment is too time-consuming to be practicable on forest fires except those of small size. When complete extinguishment is not secured, the fire is controlled by putting out the outer edge and extinguishing all burning material within a zone bordering the unburned forest. The fire is thus held within bounds. The center may remain ignited, but eventually, on exhaustion of the available fuel, it dies out. This may occur immediately after the edge of the fire is suppressed, or it may require weeks, depending upon forest conditions and the weather.

The technical details of the actual work of suppressing the fire do not differ materially whether the fire is extinguished or controlled.* In the latter case the work of extinguishing the fire is carried on only over the outer zone of the burned-over area instead of over the entire area.

When fires are controlled, in contrast to being extinguished, four methods may be recognized: the direct, the 2-foot, the parallel, and the indirect methods (Osborne 1942, pp. 53–64). The 2-foot and the parallel methods are modifications of the direct method and in most parts of the country (although found in practice) are not recognized as separate methods of firefighting. The direct and indirect methods are well differentiated.

* An exception to this statement is found in the employment of backfiring and other indirect means for controlling fires which may not be used at all in extinguishing a fire directly.

The objectives in controlling instead of extinguishing the fire are: to knock down or check the blazing front of the fire and any snags likely to cause spot fires, to cut off the outer edge of the fire from access to new fuel by building a fire line, to allow most of the interior materials to burn out but to mop up all fire on a wide marginal belt.

Direct Method

The advancing edge of the fire is attacked directly and stopped either by use of water, mineral soil, beating, or by digging a narrow line down to mineral soil and throwing the burning material back onto the burned area.

Two-Foot Method

In the 2-foot method a narrow strip is dug down to mineral soil, not more than 2 feet ahead of the fire, and the fire is allowed to burn out to the strip. The method is particularly useful if hoes are the tools available for digging, since there is danger of scattering burning material with these tools if the actual edge of the fire is dug out. There is no need to employ the 2-foot method (which is a variation of the direct method) if the edge of the fire can be extinguished without digging a fire line. When the edge of the fire must be dug out (as happens if a thick duff exists) it may be safer to dig the fire line back 2 feet from the edge of the fire rather than at the edge itself. In digging out the edge of a smoldering fire, burning portions are likely to be overlooked, whereas if the fire line is made a little ahead of the fire this will not happen.

Parallel Method

A fire line is constructed 6 to 30 feet ahead of the fire, and the inflammable material between the advancing fire and the newly constructed fire line is burned out at once. On many fires it is impossible to work right at the edge of the fire because of the heat and the speed with which the fire is moving. The parallel method enables the firefighters to work somewhat away from the heat of the fire and yet construct their line close enough so that the area intervening between the fire and the fire line will be quickly burned out. Cutoffs can be made across small indentations of the fire front, thus decreasing the length of fire line to be constructed.

Indirect or Backfiring Method

In the indirect method the firefighters drop back from the advancing fire to a firebreak or to some good natural control line or fire line which has been built as part of the suppression work, and there set backfires which are allowed to run toward the main fire but are extintinguished on the side bordered by the control line. The purpose is to burn out a wide enough strip of country ahead of the main fire so that the latter may be robbed of fuel and controlled. The method should not be employed if any of the other methods described can be successfully used.

Backfiring is risky because the backfires are likely to get across the control line and themselves develop into uncontrolled fires. This danger is intensified since the need of backfiring arises only at the times when burning conditions are such that fires spread rapidly. Backfiring may appear destructive because it may necessitate burning over a considerable area ahead of the main fire. This injury is more apparent than real if the backfiring is properly done. Properly planned and executed, backfiring burns over only areas which would otherwise be injured more severely by the main fire.

Backfires should never be started until the fire line which is intended to prevent their escape has been constructed over a wide enough front so that the backfires cannot escape around the end of the fire line. The fires should be lighted close to the line, so that they have no opportunity to gain momentum in running toward the fire line, but must burn slowly out to meet the main fire. To combat a fire coming up a steep slope the backfire should be started just over the crest on the side of the ridge farthest from the fire. Starting backfires on a slope above an advancing fire should be avoided. Should it be necessary to backfire vertically on a slope, a protecting fire line should be located straight up and down the slope and the backfiring should begin at the upper corner where the fire line reaches the ridge.

Where there is much backfiring to be done torches are needed to facilitate the operation. Various types of hand torches are available as well as pressure torches. The Mathis plow used for building fire lines in southern pine forests can be equipped with a gasoline pressure tank which is so arranged as to produce a flame 3 to 6 feet long on either side of the plow. As the plow makes the fire line it is automatically backfired.

Backfiring has proved successful as a last resort in controlling many

fires. One of the most spectacular instances occurred in the Latigo Canyon fire in the chaparral type of southern California (Turner 1936), which burned over about 15,000 acres and required the services of more than 2000 firefighters, 14 tank cars, and 9 portable pumps before being controlled by backfiring from firebreaks and other lines protected by the power pumps and tank trucks. This region, because of the high inflammability of the chaparral cover, the steep mountainous topography, and the adverse weather conditions, is characterized by fast-burning fires traveling through the crowns of the chaparral which are difficult to control except by the backfiring method.

Application of Water

The most effective method of extinguishing fires is to apply water to the burning material. However, where water supply is scanty or transportation inadequate this often cannot be accomplished so cheaply as fighting fires in some other way. The use of water in fighting forest fires has become widespread with a tendency toward increased use. Extensive use of water in firefighting on a forest property goes hand in hand with the development of the transportation system and bears relation to the natural water resources of the region. Water is heavy to carry and can be made available at the fire only as effective means of transport are developed. In many areas water for firefighting cannot be secured in abundant supply. Osborne (1942, p. 48), speaking of the Pacific Northwest, states that water is used at present on less than 10 per cent of the fire perimeters in that region and when all the equipment needed is obtained will be used on not more than 20 per cent. He believes that for many fires other means of control may be less expensive and fully as effective as water.

Water is applied in firefighting from any of the following:

- Small containers, particularly back-pack cans or bags with pump attached.
- Portable gasoline engine pumps and hose.
- Tankers, usually equipped with pumps and hose.
- Gravity system employing hose to deliver the water.

Equipment for applying water was discussed on pages 107 to 108.

Any forest fire can be attacked directly with water. In firefighting, the water is applied to the edge of the fire and the stream directed at burning material on the ground. Water is conserved and proves more effective in most fuel types if applied in the form of a fine spray instead

of a solid stream. On most fires the quantity of water is limited and must be made to go as far as possible.

In this connection mention should be made of the use of so-called wetting agents to increase the saturating action of water, thereby making a limited quantity of water go further. Already several instances have been reported of the successful results obtained by using wetter water to suppress forest fires (Kearney 1947; Anonymous 1947).

When the water is delivered at the fire it is most economically applied to the burning material by means of hand spray pumps, which conserve the water and permit its application at the exact spots and in the minimum quantities needed. Water is most effective in stopping an advancing fire when the spray is directed on the ground just in front of the flames. Mechanical force is thus exerted in combination with the wetting action of the water.

Peat fires require thorough drenching with water, but fortunately they usually occur in places where an abundant supply of water is near by and can be applied in volume by a power pump.

Water may also be applied in the form of a finely divided mist or fog from tank trucks. The fog raises the relative humidity so much that fires cannot burn if the proper type of nozzle is used (Funke 1941). The fog may be applied either with pumps producing high-pressure or low-pressure fog (Anonymous 1946). One advantage of the first is that the high pressure results in driving the moisture more thoroughly into the fuel. However, high pressure requires more expensive equipment (Everts 1945).

In operating the back-pack cans and bags the firefighter walks along the fire line, pumping as he advances. He should not stay in one spot long enough to completely extinguish the fire but should pass along quickly, even though fires may rekindle after he passes. He should be followed by other firefighters, equipped with hand tools, who completely extinguish the parts of the fire which start up after the pump man.

If the source of water supply is near the fire, as frequently happens in a well-watered country, a bucket brigade can be organized among the firefighters and the water brought in by hand. Otherwise the hand pumps must be supplied with water from tank trucks or by portable power pumps.

There are various ways of applying water furnished by power pumps. The pumps, both the portable type carried into the woods and the heavier type on a truck or trailer set up beside a water supply, deliver water through hundreds or thousands of feet of linen or rubber-lined

cotton hose at the fire line. Because of the greater volume of water supplied (15 to plus 100 gallons per minute) this should be employed only on fires requiring large amounts of water.

The portable gasoline pumps because of their lesser mobility find their greatest field of usefulness on slow-burning fires with large amounts of fuel available. Ground fires burning in deep duff or peat are best combated with gasoline pumps. Hose cannot be laid and shifted fast enough to permit using a power pump for fighting a rapidly advancing fire. Where ground fires are fought it may be necessary to soak thoroughly or even flood the layers of burning material with water delivered directly from the gasoline pumps.

Power pumps furnish a means of thoroughly safeguarding areas of special hazard and high value. They can be used to wet down the fuel ahead of the fire to serve as a line from which to backfire. Water can be advantageously applied directly to the advancing edges of the fire and also to all classes of burning material inside the fire area, such as beds of live coals and particularly burning logs and standing dead trees.

A better way to apply water with power equipment, which overcomes the disadvantage of lack of mobility and is possible on level sand plains and in open southern pine forests, for example, is to have a truck or tractor with trailer drive right along the edge of the fire applying water as it passes along.

Funke (1941) considers the 5-man suppression squad equipped with a standard tank truck and its auxiliary equipment to be the most efficient and flexible unit for general fire suppression. The power pumper increases the effectiveness of the crew about three times over those equipped with hand tools alone. Some hand-tool work usually will be needed along with the use of the tank truck and pump.

The Massachusetts brushbreaker (see page 108) is equipped with two hose lines 500 feet in length. This is long enough to allow considerable leeway in approaching close to the front of the fire or staying back from it, depending on the heat, but does not involve laying out long cumbersome lines of hose which cannot be quickly moved. The truck also has a 25-foot length of hose which can be used in protecting the truck itself from fire. The system of fighting is to drive the trucks right into the woods, breaking down trees up to 4 or 6 inches in diameter, and proceed right along the fire front.

A second truck follows with a similar equipment to mop up the fire and to take the front position when the first truck has to go out for a new supply of water. The water tank is emptied in 30 to 40 minutes. A crew of 4 to 5 men is carried on the truck. On one fire two of these

brushbreaker tanks put out 3 miles of fire in 4 hours, a job which would have required at least 100 men.

The Michigan Forest Fire Experiment Station has perfected a combination of tractor and pump unit with a trailer to carry the hose. The advantage of this unit is that it can go wherever a tractor travels, so that swamps and other difficult locations impassable for a truck are accessible to it.

By having several pumps working in relays water can be brought a long distance and elevated many hundred feet. Although a single portable pump theoretically can pump water up to an elevation of more than 400 feet, yet in practice it is better to plan on raising the water 200 to 300 feet with each pump.

Where the water table is within 22 feet of the surface and the water is contained in a pervious soil layer, an abundant water supply can be developed quickly by sinking temporary wells. Stewart (1934) has demonstrated the practicability of sinking a well casing by hydraulic pressure secured from the ordinary portable power pump used in firefighting. The well can be brought into production within 8 to 30 minutes from the time drilling is started. Where surface water is scarce and the underground water table high, the usefulness of power pumps is greatly enhanced by this discovery.

If the water supply is located above the fire, as may occur in mountainous regions, gravity can be used to bring the water down through a hose line without any pumping.

Experimental use is now being made of water and chemical filled bombs dropped from aircraft on small hot fires (Hall 1947). The purpose is not to extinguish the fire completely but rather to check its rate of progress and thus give more time for the fire to be reached by firefighters.

Extinguishing Fires with Soil

On a large proportion of fires soil is the sole or an important means of extinguishing the fire. It is more readily available than water, and its use may mean a saving of time in suppressing the fire. Though not as effective as water, soil smothers the fire and cools off the burning material. It is best applied with a shovel. A hole is first opened up through the forest floor and soil free from undecomposed organic material is thrown on the burning material. Soil can be employed effectively both for arresting the advancing edge of a surface fire and for extinguishing burning material within the burned-over area.

Beating-Out

There will be times when water or soil is not available or tools to apply them are lacking. Under these circumstances beating-out may be employed. In this method the advancing edge of the fire is struck glancing blows with some appropriate tool. The term "beating" though commonly used is hardly applicable, since the action is more a sweeping or pushing-in of the fire toward the burned-over area than an actual beating-out. A stroke vertically downward has the effect of scattering the blazing material and may result in a faster spread. If the stroke is an inwardly glancing one the burning material is carried back onto the burned-over area and separated from new fuel.

The method is best suited to fires that are feeding on a light surface litter. It cannot be used effectively in dense brush. One advantage of the beating method is that tools to accomplish the work may be improvised from branches broken off in the woods. Better tools for the purpose are strips of wet burlap sacking, brooms of all types, and particularly swatters and the rotary fire mop (see page 105).

The swatter is an excellent tool for use on grass fires (Sykes 1940).

Another fire equipment item with a sweeping and smothering effect on the fire is a truck equipped with two metal bars extending to one side to which are attached drags made of chain mesh with an asbestos mat cover (Wershing 1942). The outfit can be used on areas that are relatively flat or rolling and covered mainly with grass or very light shrubs. The chain mesh serves to break up the burning material and mix it to some extent with the top soil. The asbestos mat serves to shut off the oxygen from the burning material. One trip may or may not completely put out the fire, but at least it deadens it to a point where it can be mopped up. Usually the truck runs along on the outside of the fire, dragging the mats directly over the fire. It is possible, however, to drag the chain outside the fire, creating what amounts to a fire line, and let the fire come to this fire line.

MAKING AND HOLDING FIRE LINES

All methods of suppressing fires, except those which directly extinguish the fire, require more or less fire line construction. These lines are of temporary character, and less elaborate than the firebreaks previously described (page 97). Their location is determined primarily by the shape and location of the fire.

The output of held fire line which can be produced by firefighters is governed not only by the forest or fuel type, difficulties of work, and firefighting method used but also by the skill in handling men and in firefighting displayed by the men in charge of the crew. If costs of suppression are to be kept relatively low, a high rate of held line per man must be obtained. Rate of construction is commonly expressed as the number of chains per man-hour, or man-hours per chain of held fire line.

Fire lines constructed by hand labor range from a fraction of one man-hour per chain of held fire line to more than 40 man-hours under conditions of extraordinary difficulty. A table based on an analysis of fires in the northern Rocky Mountain region computed by Hornby (1936, p. 41) shows a range in number of man-hours per chain of held line from 0.2 to 10.8 hours.

These rates of work may appear exceptionally low, but that they are typical of the difficulty of fire line construction under severe mountainous terrain is indicated by the findings of Hanson (1941), for southern Idaho, who reports that the average rates of line construction per man-hour varied from 0.08 chain under extreme resistance to control conditions to 3.18 chains when resistance to control conditions was very low.

Although methods of constructing temporary fire lines vary, depending on topography and forest conditions, yet all these temporary fire lines are built to fulfill the same general requirement. They should provide a narrow strip cleared of brush and, except when water or beating-out is to be used, should be cleared down to the mineral soil, which in itself may serve to stop some fires and act as a control line from which to start backfires. Exceptionally inflammable material such as snags and down logs, must be felled or removed from the fire line so that the fire, as it reaches the line, will find less fuel to feed upon and be easier to extinguish. The fire line must be cleared sufficiently to afford room for the firefighters to work effectively in extinguishing the fire when it comes to the line. When running horizontally along slopes with fires burning on the upper side, the dirt strip of the fire line should be in the nature of a ditch or gutter sufficiently banked to stop and hold burning embers and cones which may roll down the slope.

Wherever power equipment is available and the land is not too rocky to prevent its operation it should be employed in preference to hand labor because of the time saved.

Machinery such as plows, drags, graders, and trenchers of various types provides a cheap, rapid method of constructing fire lines around

going fires (see page 106). The cost of fire line construction is reduced thereby often to a tenth of that of hand labor. For efficiency the equipment must be adapted in speed and power to the specific forest conditions encountered.

Plows for use on fire lines must be of a strong construction with the type of moldboard suited to the soil and tree-root conditions encountered. The plow should operate independently of a plowman. In open country trucks can occasionally furnish motive power, but usually tractors are needed. Horses cannot accomplish the work performed by a truck or tractor but are often of service when these machines are unavailable or cannot be used.

Plows mounted on rubber-tired wheels are now in use. One advantage of this arrangement is that the plow can be attached as a trailer behind a car and travel on its own wheels to the fire.

Where large crews were employed in constructing fire lines by hand labor the practice until recent years usually was to employ the sector method. In this method the large crew was divided into smaller crews and a short sector allotted to each. When a small crew finished its allotment it stepped forward past the rest of the men and started another sector. The results in the way of line produced per man-hour were not satisfactory.

Then what has been termed the one-lick method was tried in several places instead of the sector method in an effort to speed up the rate of fire line construction (McReynolds 1936; Campbell 1938; and McIntyre 1942). The principle of the one-lick method is that a fire line should be built about as fast as a man can advance through thick brush occasionally hacking off limbs in his way and should be improved a little by each succeeding man. In operation the crew is formed in a line and follows the leader, each man doing a little work as he passes along but not stopping more than a moment in a place. The men are equipped with tools appropriate for the kind of work their position in the line will give them, for example, the axes coming first and the shovels last. The results showed a significant increase in amount of fire line built per man under this method as contrasted to the sector method. However, it has the disadvantage of being a very tiring operation and one in which a crew could not be expected to work more than 4 hours without rest. In fact, better results were secured where stops were made as frequently as every 25 minutes.

The next development was known as the progressive method (Cliff and Anderson 1940). The essential point here in contrast to the one-lick method is that groups of men (each group equipped with a cer-

tain type of tool) move forward progressively as a unit although each individual has a definite distance over which he completes the fire line before moving up. For example, a 40-man squad might be divided into a straw boss of the fire line, a group of ax men, another group with Pulaski tools, another group equipped with hoes, and finally several shovel men for backfiring and holding. The units with a given kind of tool would complete their work—the ax men, for example, would finish the ax work—for a portion of the line and then move ahead as a unit, always keeping their relative position in the crew. This method was further refined, under the name of the progressive step-up organization, by having the men spaced very regularly and moved forward on the order of the straw boss when a 15-foot section was completed (Anonymous 1940*a;* Hulett 1940).

The progressive method now appears under the name "Functional Control Line Organization" as the standard practice in Region 6, U. S. Forest Service (Anonymous 1945, pp. III 1-18 to 1-21), where it is considered "the most effective system of organizing men to obtain their maximum output of held line."

As now used in Region 6, men or machines or both are assembled in one file and then advance constructing the fire line as they progress, without shifting relative positions in the file. Progress is rapid following closely after the line locator. Men are definitely spaced so as to avoid injury and are frequently given brief rest periods.

A particularly effective system of crew organization for controlling fast-burning fires in light grass fuels where soil is readily available is the spinning fireman or Austin rotary organization method (Lindh 1940; Anonymous 1940*b*). This method employs a crew of not over 5 men, each equipped with a long-handled shovel, who remain in the same relative position while fighting the fire. The first man, after filling his shovel with mineral soil, steps close to the fire edge and while advancing whips his load of soil as hard and as far as possible up the fire edge, effectively knocking out the fire for several feet. The first man then moves one or two steps away from the fire edge and the second man repeats the same operations as the first man. The movement continues and gives the appearance of a 5-man wheel moving along the edge of the fire as fast as men ordinarily walk.

Mechanical fire line construction in the Southeast as contrasted to hand-tool work results in greatly decreased costs and more effective fire control. Hartman (1947) describes how this has been accomplished by increasing the speed of attack through development of three sizes of plow units: the light Pal plow for the grassy, open, longleaf-

pine type; a middlebuster, for the hill country up to 30 per cent slope; and a heavy plow for the Florida and Carolina coastal areas with a luxuriant cover.

The Pal plows a furrow 28 inches wide at the bottom and 4 feet at the top at a rate of 1½ to 3 miles per hour, while the heavy plow makes a 5-foot line at a rate of 1 mile per hour.

The method of using these units consists in having a crew composed of lead man, tractor driver, backfiring torchman, and follow-up man behind with a back-pack pump and flap. Suppression by these mechanical units costs $13 as against $57 per fire for hand-tool work. The average area burned per fire was 34 acres for fires fought by the mechanical unit as contrasted to 150 acres on the other fires.

The progressive development of the fire line, as a crew equipped with a variety of tools advances over the line, was practiced even earlier in the Northeast and elsewhere in suppressing fires with water combined with hand-tool work. Forest fire crews in Connecticut equipped with back-pack pumps and hand tools were instructed (Lathrop 1932) to extinguish fires by continuous advance, the first men in the crew knocking down the flames while those who followed completed the job of control.

After the first advance of the fire has been stopped at the control line the next step is to make the fire line permanently secure against fires which may later be fanned into flame and threaten to pass the line. Standing dead trees are particularly dangerous, since burning embers may be blown from them for considerable distances and start new fires across the line. To prevent such consequences in all four methods of controlling fires—direct, 2-foot, parallel, and indirect—all fires on a zone one to several hundred feet in width along the border of the burned area must be extinguished. This is termed "mopping up." The work consists of going over the area systematically felling and suppressing the fire in all burning snags and putting out completely all smoldering fires. While the mopping-up work is in progress and after it is completed, a patrol should be maintained along the control line. The duties of the patrolman are to find and extinguish any fires that may start across the control line, to improve the fire line where needed, and to put out any burning material inside the fire area which threatens to spread fire. The patrol should be continued until danger of fire crossing the line is eliminated. This condition may not be reached for several days. The importance of careful execution both in the mopping-up work and the patrol of the control line cannot be overemphasized. Lack of thoroughness in these respects often results

in the fire breaking through onto unburned territory where it must be controlled anew.

RELATION OF FIREFIGHTING METHOD TO TYPE OF FIRE

A peat fire should be fought by deep trenching to the mineral soil beyond the edge of the fire. The trench should then be flooded with water. Where water cannot be obtained, the trenches must be patrolled until the peat within the burned area is entirely consumed and the fire is out. Duff fires also must be trenched to the mineral soil. They may be extinguished or be controlled by the direct, 2-foot, or parallel methods. The indirect method is less useful since it may take a long time for the duff to burn out completely, during which time the smoldering fire in the duff is a menace. It is better to trench close to the duff fire.

Running crown fires in heavy timber usually cannot be fought directly. Dependent crown fires sometimes may be attacked with tanker units. In fighting such fires advantage must be taken of the relatively cool humid periods which come each night. At that time the fire very likely burns only as a surface fire and can be fought. If a running crown fire is to be stopped as it advances through the crowns it must be accomplished by backfiring.

Surface fires are so diverse in character that all methods of firefighting are useful at one time or another in combating them.

SIZE OF CREWS

A satisfactory size for a firefighting crew is from 3 to 40 men. It is usually better to have less than 10 men in a crew. Studies have shown that as the number of men in a crew increases the length of held line constructed per man decreases (Matthews 1940). On large fires when hundreds of men may be employed they should be divided into small crews of about 10 men under a single foreman or straw boss. Whatever the size of the crew, each man should have definite duties assigned to him. If he is a member of a permanent crew these duties are the same for each fire. The principle throughout should be that of fixing the responsibility for given portions of the work. Particularly on a large fire, the firefighters may be so scattered over a wide territory, often in dense timber or brush, that it is difficult to control the work efficiently and to have all portions of the fire covered, unless definite allotments as to the kind of work and the area upon which

it is to be done are given to each crew and to the individual members of each crew. The duties assigned to a crew of a given size must, of course, vary depending upon the forest or fuel type, the tools and equipment available, and the burning conditions. There should be a proper balance between men assigned to work with different tools so that the attack as a whole may progress smoothly. The functional control line organization as now developed provides against such defects.

PLAN OF ATTACK

If the fire is small enough or the crew large enough, the attack may be made simultaneously on all sides. This procedure, however, would not be in harmony with the idea of functional control line organization. As a general rule the head or front of a fire should be attacked first. This is the sector of the fire which is most active and dangerous. Once the head is stopped the flanks and rear can be controlled with relative ease. If the crew is large enough or the fire small the fire-fighters may start at the head of the fire and, dividing, may work in opposite directions across the head of the fire, then down the two sides, and finally meet in the rear of the fire. If the head of the fire cannot be attacked directly with success, then the flanks on the two sides of the head should be attacked and the attempt made to work toward the head, gradually pinching it out. Most fires can be attacked right in front, although to inexperienced men it may seem impossible. Special cases are likely to be encountered at any time where good strategy attacks first at some special point other than the head. Where, for example, the head fire is running directly toward a near-by wet swamp or where a valuable stand is threatened by the advance of one of the flanks, the attack should be varied to fit the circumstances.

Advantage should always be taken of any natural features, such as lakes, cliffs, or swamps, toward which the fire may be directed, by selecting the portions of the fire front which are attacked first.

On fires of such a size that the fire boss, the man in charge of the fire, cannot see at once the critical points requiring attack, it is essential that he reconnoiter either by going around the fire or by obtaining a view over the fire area. On large fires very often one man, the fire scout, is assigned the job of doing such reconnoitering as well as acting as a liaison officer between crews working on different sectors of the fire. For scouting, aircraft are of great assistance. Helicopters may become very useful for planning the attack and directing the work

of the firefighters on large fires. The use of a loud-speaker would enable an observer in a helicopter to direct the ground forces in the attack.

The time of day has little significance in affecting the starting or ending of the attack on most forest fires. The firefighters begin work when they get there and should stop (except for meals and rest periods) only when the fire is extinguished or controlled. On fires which last more than one work day, conditions are somewhat different. Men cannot work continuously without rest. Their rest can be so planned as to take advantage of the periods during the 24 hours favorable to firefighting. The diurnal changes in relative humidity make the early morning hours, starting at daybreak, the most effective for fighting fires and the early afternoon the least.

Night will be a better time to fight fires than the hotter half of the day if adequate lighting facilities are made available. In general, night fighting should be favored if the fire can thereby be controlled before the burning period of the following day. On extra-period fires which must be fought for several days more effective results may be secured by putting the crew to work at daybreak.

Where night fighting is advisable a lighting system must be provided. With adequate lighting arrangements, there are many forest types where night fighting can be made more effective than daylight fighting.

The hourly fluctuations of weather should be followed or anticipated and their effect on burning conditions predicted. Advantage should then be taken of these predictions, both the methods and the time and place of fighting being changed if necessary.

In particular, it should be recognized that the direction of the wind and to lesser extent steep slopes determine the location of the head fire. If there is no wind or if a change in wind direction is expected, that sector of the fire which promises later to be the head should be controlled.

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CHAPTER 14

Forest Fire Insurance

Fire insurance on forest property cannot be secured today in the United States at low enough rates to make the coverage attractive to landowners. This is an unfortunate situation because of the aid which fire insurance coverage could have upon stabilizing the growing of forest crops.

The desirability of forest fire insurance was recognized about 1917 by a few men who organized a company known as the Timberland Mutual Fire Insurance Company for furnishing forest fire insurance. They operated only in New Hampshire and apparently were successful financially during the brief period—less than 2 years—in which they operated (Brown 1926). Their minimum premium rate was 2 per cent, and consequently a large volume of business was not secured. After demonstrating that it was practicable to sell forest fire insurance they turned over the business as a successful going proposition to the Globe and Rutgers Insurance Company, who continued to carry the business but without any special effort toward enlargement. Undoubtedly the time was not then ripe for starting forest fire insurance on a large scale because adequate fire control had not been developed over much of the forest area in the United States.

In the years that have elapsed since this initial effort was made to develop forest fire insurance, the status of forest fire control has changed remarkably for the better. The protection now afforded forest lands in most parts of the country is not at all incommensurate with that given building property.

The time may now be ripe to develop forest fire insurance on a large scale. What are the advantages to the forest landowner of having fire insurance coverage on his forest? The argument that the

forest owner is already paying for fire protection and should not plan also to pay insurance premiums is just as ridiculous as such an argument applied to fire insurance on buildings would be. House owners pay through taxation for the protection of their buildings and other burnable property by organized fire departments and then also take out fire insurance policies on these same buildings.

The principle involved in forest fire insurance is the same as in other types of fire insurance, namely, that the owner insures a portion of the risk * which is too great for him to take because of the relatively small size of his property. He protects himself by obtaining the help of an insurance company which can afford to accept the risk because of the enormous area covered by its insurance and by the scattered distribution of the individual areas which through the operation of the laws of chance makes it unlikely that large losses will be suffered simultaneously on all areas insured. The total cost which he will be called upon to pay when carrying forest fire insurance will, of course, be increased somewhat over his present annual expenditure for fire control. But the advantage to him is that, instead of having to bear his own losses, he will have them covered. This service will, in the long run, be a money saver for him and will create security in forestry operations just as fire insurance policies on his buildings do.

The first and most important advantage of forest fire insurance is that, by a small annual payment which can be budgeted and charged as a current expense, the owner is relieved of the fire risk.

Another advantage is that the owner's credit rating is strengthened because he now has a property relieved of fire risk upon which greater loans can be secured. He is also encouraged by his insurance of the risk to stabilize his operations for continuous production instead of liquidating his forest capital because he fears a heavy fire loss.

Forest fire insurance is not a substitute for fire protection but a supplement to it. Organized forest fire protection does not guarantee that there will be no forest fires and no losses any more than the maintenance of an expensive fire department in a large city guarantees that there will be no building fires. The forest fire organization and the city fire department keep the losses at a reasonably low level but do not obviate the need for fire insurance in the forest or in the city.

* The reader should keep in mind that, in fire insurance parlance, risk refers to the chance of loss or the perils to the subject matter of insurance covered by the contract. Likewise, hazard as used by fire insurance companies includes all the factors which affect either positively or negatively the safety from fire of any subject matter of insurance.

Since organized forest fire protection now makes possible a safe insurance business in large sections of the country and there is a distinct need for owners to have fire insurance coverage, an effort should be made to put the matter on a business basis.

Shepard (1937 and 1939) has presented the results of forest insurance studies made in the Pacific Northwest and in the northeastern states, which bring out the principles involved in developing any scheme of forest fire insurance. His information has been freely drawn upon in this chapter, and his methods and conclusions should be carefully studied by those interested in forest fire insurance.

The first essential in any scheme of forest fire insurance is that fire risks be analyzed for a given region over long enough periods, such as 10 years, so that an accurate basis for establishing rates may be obtained. Methods of rating are in principle those customarily followed in fire insurance practice and present no particular difficulties. They provide for a base rate with additional charges for conditions (hazards) which add to the danger and for omission of any of the details needed for adequate protection. Discounts may be allowed in the case of especially well-protected properties.

Although it is true that through a large part of the United States today forest property is already an insurable risk, it remains to establish the premium rates which should be used. There are some sections of the country such as parts of the southern states, the northern Rocky Mountain region, and the sand plains of the Lake states where forest property is still uninsurable at reasonable rates. Undoubtedly forest properties in these regions might be insured at high but prohibitive rates.

Once rates have been established on a sound basis in a given forest region, two problems must be met; the first is to interest forest landowners in taking out the insurance, and the second is to interest fire insurance companies in writing it.

The lethargy of forest owners will have to be overcome by publicity as soon as insurance companies are ready to take the business. All forest organizations should be glad to assist in supplying publicity, considering the important benefits accruing to their members from the forest fire insurance coverage. Self-interest will impel all far-sighted owners other than those big enough to carry their own risks to take out the insurance. When the matter is properly presented, it is probable that a large proportion of forest landowners will welcome the chance to get forest fire insurance. The crucial point from the forest owner's standpoint is the rate, which must be reasonably low.

Studies made by Shepard indicate that the average rates for insuring forest property against fire, including the ordinary loading for agents' commissions and expenses, will compare very favorably with those now being used in insuring other classes of property against fire.

Shepard believes that an average rate of 0.45 per cent would provide a profitable insurance business in the Pacific Coast states if premium income amounted to $150,000. At this rate, forest owners should be able to afford and profit by the insurance coverage. If this income reached the $1,000,000 mark a reduction in average rate to 0.30 per cent could be made safely. Probably in most of the northeastern territory average rates could be lower than in the Pacific Coast states.

Interesting insurance companies in writing forest fire insurance at rates which will appeal to forest owners may be difficult because the opinion is prevalent, first, that forest fire protection is so inefficient that the business of insuring forest property against fire is very dangerous and can be done safely only at a very high rate, and, second, that no worth-while volume of business can be developed. This last point is certainly correct if the old rates of the Timberland Mutual Fire Insurance Company are to prevail.

Insurance companies must be convinced that the business is safe at rates low enough to get and hold a big volume of business before they will undertake the job.

Shepard's work has gone far to establish the fact that it is possible to develop a scientifically operated system of rate making on forest properties along the lines already in use by fire insurance companies.

In the past when insurance companies have taken up the insuring of new types of property they have started by setting high rates to protect themselves and have gradually lowered these rates as volume of business increased, reserves were accumulated, and they became expert in appraising accurately the risk in insuring the particular type of property. Shepard indicates that this method of experimentation is unsuited to forest fire insurance because the margin of profit is small in the forest industries and the landowners would not pay the high premiums, and, furthermore, that experimentation is unnecessary since the basis for making reasonably accurate rates on forest property is found through analysis of existing forest fire statistics.

In addition to the necessary capital as requirements for the development of a profitable forest fire insurance business, there must be a careful selection of risks, frequent inspections of a large percentage of the properties covered, attention to the character of the assured, proper appraisals and valuations, a good distribution of liabilities sup-

plemented by intelligent reinsurance, a sympathetic attention as concerns forest owners, and honest dealings.

A large volume of business should be available provided rates comparable with building fire insurance are made effective. A business of at least $2,000,000 in annual premiums is quite possible for forest fire insurance taking only the relatively safe risks in the best-protected regions.

There are approximately 90,000,000 acres of privately owned forest land in the northeastern, Middle Atlantic, and Pacific Coast states already under protection. On the assumption that one-half of this area or 45,000,000 acres would be covered by fire insurance with an average value of $10 per acre and an average premium rate of 0.45 per cent, the total annual premium income would be in excess of $2,000,000. With this volume of business it is believed the rate could be lowered to 0.30 per cent and the volume of business be doubled.

As fire protection is strengthened in other sections of the country and a larger percentage than one-half of the forested area in a given forest region is covered, the total premium income is likely to expand correspondingly.

Forest fire insurance, once it operates on a commercial scale, should be a great stimulus to organized, effective fire control over the forest areas of the United States. Then the average owner will fall in line and find that having such insurance is a necessary item of current expenditure, safeguarding his timber resource. He will then discover, just as he has already done in carrying building fire insurance, that to get favorable returns he has to obey certain insurance regulations and provide adequate protection for his property. Hence he becomes more interested in seeing that such protection is provided.

The insurance companies as soon as they cover forests will have a direct interest in the maintenance and improvement of forest fire control and will work toward that purpose. This has been the result of the development of fire insurance for other classes of property and is expected in relation to forest fire protection.

Encouragement of all sound forest fire insurance projects would be an exceedingly worth-while activity for the federal government and for the states to undertake. In this connection it is interesting to note that the so-called Hook Bill which was introduced in Congress in 1946, but failed of enactment as a law, included among its provisions for federal crop insurance the coverage of insurance on growing forests under conditions to be prescribed by the Secretary of Agriculture. Federal action may seem unnecessary since the business should be suffi-

ciently profitable to interest private companies. However, participation by the federal government, at least for the first few decades until an adequate reserve to cover conflagration hazard is built up, would doubtless have a stimulating effect upon early development. The government might at least provide loans to the companies in case conflagrations occurred in the early years. After conflagration reserves had been built up, such assistance would no longer be necessary.

Shepard considers that an insurance pool of several of the existing fire insurance companies would be the logical method of starting forest fire insurance on an adequate scale.

Should it prove impossible, after the case has been adequately presented to the insurance companies, to find one or more companies which would furnish forest fire insurance at reasonable rates, then the need for a public-owned insurance company would be clearly indicated and appropriate action should be taken to that end.

FOREST INSURANCE AGAINST OTHER INJURIES THAN FIRE

Fire is undoubtedly the risk that can first be covered by insurance. Once this is satisfactorily provided for there may be possibilities of insurance coverage against other injurious agencies affecting the forest. At the moment practical development along this line may seem remote. However, the transformation through insurance coverage of quantitatively unknown loss into known current annual expense and the change in management from an exploitation to a sustained-yield basis will have a stabilizing effect upon forest industry. These facts justify further study of the insurance situation.

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CHAPTER 15

Protection against Injurious Plants

DEFINITIONS

From the standpoint of forest protection all plants which in one way or another cause injury to the growing forest crop should be included in this discussion. Injurious plants as thus defined may be grouped into three general classes: fungi, mistletoes, and forest weeds. Plants which cause damage to cut forest products are not considered here as they fall outside the scope of forest crop production. Preservation from decay and other injuries of cut wood is an important problem for the wood anatomist but not for the silviculturist.

Protection against injurious plants has often been regarded as synonymous with the subject of forest pathology, and this in turn with tree diseases. Hubert (1931) gives the following definition of tree diseases: "A tree disease may, therefore, be defined as any interference with the normal functioning of a sound tree resulting in disturbed or abnormal physiological action or the deterioration of any of its parts." This is an exceedingly broad definition, so comprehensive as to take in injurious activities of practically all agencies affecting forests such as fire, insects, animals, atmospheric factors, and man in so far as they interfere with the normal functioning of trees. In other words, protection against tree diseases if carried to the logical conclusion becomes practically synonymous with forest protection as a whole.

This conception is too all-inclusive to be advantageously used in a general study of all the agencies against which the forest needs protection. As a matter of fact, forest pathologists have never extended their consideration of tree diseases to the full limits which this definition makes possible. For our purpose the term tree diseases will be

used in a relatively narrow sense as applying only to the plants that directly attack trees.

The present chapter is devoted to consideration of the injuries to the growing forest caused by harmful plants which include principally fungi, mistletoes, and forest weeds. The effects of the first two of these classes of plants may be spoken of as diseases, but the effect of the last class is not usually classified as a disease.

GENERAL CHARACTER OF INJURY

Every part of the tree both above and below ground is susceptible to injury by other plants: the roots, the trunk including bark, cambium layer, sapwood, and heartwood, the branches, needles, buds, and seeds. Some of the tree diseases are of an epidemic nature, and those caused by certain plants imported from foreign countries, such as the chestnut blight, may be so virulent continuously as to accomplish commercial extermination of their hosts. Other tree diseases may become epidemic periodically as the result of favorable environmental conditions. Still others though always present in the forest and a constant source of loss rarely if ever develop into an epidemic stage.

As pointed out in Chapter 1, both insects and fire usually are rated more destructive in their effects upon the forest than the plants covered in this chapter. Yet individual plants have the capacity for inflicting injury on a large scale. Witness the chestnut blight, which in a period of about 50 years after its introduction into this country exterminated the chestnut as a commercial species over all its range and is still present in an epidemic stage. The rapidity of this attack and the completeness of the destruction over a large region are not characteristic of the work of most injurious plants. On the average they work more slowly than fire and insects, are disseminated unnoticed, may exist within their tree hosts for many years before revealing their presence, and often take several decades to accomplish the death and destruction of a single tree.

The extent of the damage caused annually by plants has not as yet been even approximately estimated. The individual species are so numerous, the damage caused is so varied both in nature and in amount on individual trees in the same stand, and so much of the damage is invisible, occurring inside the tree, that it is practically impossible to make such an estimate. That the annual damage to standing trees from the numerous injurious plants affecting them runs well up into

the millions of dollars is unquestionable, even without including the abnormal epidemics such as that of the chestnut blight.

The injury from plants may be classified under one of two types. The first is physiological, resulting in interference with the life processes of the tree. Such interference may be so severe as to kill the tree or cause deformation of a part or of the whole tree. Sometimes the result may be simply a reduction in the growth rate of the tree.

The second is technical. Injury of this type may be invisible externally, like some heart rots, and cause no interference with the life processes, at least until the technical value of the tree is practically destroyed. In other cases external deformation or decay may lessen or ruin the value of certain portions of the tree for commercial use.

INJURIES FROM FUNGI

Among the plant diseases of forest trees, fungi are of primary importance. The fungi which attack the growing forest are parasitic. Saprophytic fungi obtain their nourishment from dead and dying wood and not from living trees. With the saprophytes the silviculturist has little concern since his forest crop is not attacked. Indeed, the saprophytes serve a beneficial function in the forest by hastening decay and the return of dead organic materials to the soil. Parasitic tree diseases, on the other hand, prey upon living trees and directly affect the yield and quality of forest crops. Under favorable conditions some fungi, generally classed as saprophytic, attack living though usually weakened trees. They then become parasitic in nature.

The two most destructive classes of fungi attacking forest trees are the wood-destroying heart rots and the epidemic diseases which are virulent enough to cause rapid death of their host over wide areas of the country. Where a fungus of this epidemic type becomes established it causes more widespread and wholesale loss than the heart rots. Fortunately there are very few fungi of this type in the United States, and those few that occur are importations from other parts of the world. The destructiveness of such an epidemic is augmented by the fact that it may kill outright trees of all ages and thereby exterminate a species commercially. If the species exterminated is the chief tree for management in the region, as was the chestnut on the eastern seaboard, tremendous damage results to the productiveness of the entire forest area.

Fungi causing decay, in contrast, work very slowly, and, though ultimately they may totally destroy the timber value of the stand,

they require decades to accomplish this result. Furthermore, most of these decay fungi do not attack young trees but develop only after the trees are fairly well along in life because they live only upon the heartwood which is not formed in the early life of the tree. There are a great many species of decay-causing fungi, and practically every important timber tree is susceptible to attack by one or more species. Species which work principally in the heartwood and those which work in the sapwood are both found. Some of the fungi that cause decay in the sapwood work with far greater rapidity than the typical heart rots and may ruin the sapwood zone in the tree within a relatively few years. They can attack young as well as old trees since the sapwood forms as soon as the tree begins life.

The cumulative destruction of timber by these fungi is enormous in the virgin forest, for here the fungi may have been growing within the old trees for several hundred years and have rotted the entire tree except a relatively thin shell on the outside. The second growth forest which follows present-day cuttings in old growth timber will in its turn be harvested on a shorter rotation and will not afford time for the heart rots to develop so extensively. Thus once the virgin forest is utilized heart rots will be of relatively less importance among the injurious fungi than they are today.

The root rots are one of the most threatening types of fungi because they work and spread underground. Hence infected trees cannot be removed as sources of further infection as can those infected with species of decay fungi whose spread is restricted to the above-ground portion of the tree. Another serious feature of the root rots is that, unlike the heart rots, they are not restricted to older trees which have heartwood but may be prevalent in stands of all ages and may kill even young trees. The action of root-destroying fungi may be a large factor in accounting for losses from windthrow in certain localities.

Other types of fungi, among which are the stem and branch cankers and rust diseases on foliage, result at least in loss of increment. Serious cankers of the *Nectria* and *Strumella* canker type may destroy the tree. The *Strumella* canker attacking oaks and the *Nectria* canker attacking many hardwoods cause the formation of cankers on the main stem and branches. These cankers gradually spread, and several occurring in a short space along the stem or even a single one may girdle the trunk. If the tree is not girdled it may be broken over at the point of attack. Although single scattered trees may be attacked the damage in the aggregate is very large. It is particularly bad because the best dominant trees in the stand may be attacked.

Fungi other than the heart rots are prevalent in stands of all ages, often attacking young trees and causing serious loss in middle-aged stands. In second growth timber they are likely to assume a role of major importance as compared to the heart rots.

Many of the fungi which are prevalent in stands past the reproduction stage kill or severely injure only occasional trees throughout the stand. These trees may be widely scattered or of too poor a quality to pay to salvage. Injury of this sort, though it often appears serious, in reality may act as a crude thinning and can be disregarded unless it is too heavy or the better trees are attacked. Where the good species or the most promising individuals are the ones attacked by the fungus the results of such reduction in density of the stand may be exceedingly bad.

Fungi are particularly destructive in forest nurseries because of the favorable conditions prevailing for their development. Here the trees are small and tender and grow in densely stocked beds containing only individuals of a single species. Death of the trees attacked, rather than partial injuries or reduction of growth, is characteristic of the work of fungi in nurseries.

A variety of fungi attack the young trees, including damping-off fungi, root rots, diseases of the needles, stem rusts, and molds on stock buried under snow. One of the commonest types of disease is caused by the damping-off fungi which attack only the newly established seedlings soon after they have started. When uncontrolled, this disease causes wholesale losses in coniferous seedbeds amounting sometimes to the destruction of entire seedbed projects. The seedlings, attacked at the surface of the ground, quickly wilt, and perish within a very short time. Root rots, fungi attacking the needles, stem rusts, and mold may cause death of the seedlings attacked and prove a serious cause of loss in a given nursery.

Method of Entrance

Parasitic fungi though able to attack living trees must have a suitable opportunity for gaining access. In young trees, before cork is formed in the bark, fungi often are able to enter through the uninjured bark if climatic conditions are favorable. More mature wood can be attacked only through a wound or opening in the protective bark covering. Such wounds may be created in a variety of ways, as for example by fires, lightning, frost, storms, insects, branch stubs left by natural pruning, or wounds caused by logging. Artificial pruning of

live limbs may result in the entrance of fungi, although this subject has yet to be thoroughly investigated. Spaulding, MacAloney, and Cline (1935) found that, where live limbs over 2 inches in diameter were cut on eastern white pine, heartwood was exposed and infection by the mottled bark disease occurred. Some fungi enter through leaf stomata. Contact between roots of neighboring trees may result in infection of a sound tree by an adjoining diseased tree. With western white pine (Weir 1919), branch stubs furnish the principal points for attack; with white fir and incense cedar, fire, frost, and lightning are largely responsible (Meinecke 1915; Boyce 1920). Decay in the hardwoods of the Mississippi delta is correlated with the occurrence of fire scars (Hepting 1935).

Sometimes decay progresses so rapidly after trees are fire scarred that unless salvaged immediately after a fire the scarred trees will within a few years be rendered unmerchantable through the attacks of fungi causing sapwood rot (Stickel and Marco 1936).

The presence of fungi is revealed readily by the appearance of the fruiting bodies springing from the soil close to the base of infected trees or parts of the tree above the ground. Sometimes other parts of the fungi such as the mycelium can be seen. Where sporophores or other parts of the fungi are not in evidence there may still be disease-causing organisms within the trees. Although the fungi themselves, if sporophores are lacking, often are difficult to detect without dissection of the suspected diseased portion and sometimes necessitate a microscopical examination, yet there are numerous external signs of a diseased condition which indicate their presence. Unusual swellings of the butt section of the tree or around branch whorls, exudation of pitch from branch stubs or wounds, dead and dying leaves, twigs, and larger portions of the tree, deformities or unusual growth forms, and wilting of young plants are among the numerous indications of plant disease.

It is not always safe to jump quickly to a diagnosis of the disease from a given symptom. Other agencies, such as insects or fire, may produce in certain cases practically the same symptoms as fungi. Frequently expert knowledge on the part of the diagnostician, giving due weight to a combination of symptoms, is needed to identify the disease. A hollow trunk, which sometimes can be seen or else be discovered by means of soundings on the butt or by taking a boring with an increment borer, is likely to indicate the presence of heart rots.

A humid atmosphere, at least in the zone in which the fungi are developing, favors their growth because both the mycelium and the sporophores dry out very easily and require large amounts of water.

The forest regions where fungi are found in greatest profusion have humid, relatively warm climates which produce dense forests. Within such regions the stands growing on damp soils are likely to show the greatest injury. Environmental factors such as temperature, light, and moisture are of fundamental importance in keeping the trees themselves in a thrifty, vigorous state and in establishing conditions which will be favorable or unfavorable for the development of tree diseases. The effect of climatic factors apparently is not the same for all groups of fungi.

There are always abundant opportunities for a fungus to enter a tree through wounds, such as fire scars or abrasions of the branch, dead branch stubs resulting from natural pruning, and leaf stomata. Whether or not a given fungus attacks the vulnerable points on a tree depends upon its presence in the region and upon the existence of the right environmental factors.

Beneficial Effects

The influence of fungi is not entirely injurious. They may be beneficial in destroying harmful insects and in accomplishing the rotting of the slash, thereby reducing the fire hazard and increasing the humus supply. Fungi are of value in forming mycorrhiza. Mycorrhiza fungi form layers over the small tree roots which carry on absorption from the soil. This increases the surface area of these absorption organs, making it possible for the mycorrhizal plants to absorb more nutritive substances from the soil. However, Hartley, Boyce, and others (1933) state that it is questionable whether mycorrhiza are always beneficial to the trees, although the right species of fungus will be helpful. Nitrogen-forming bacteria, which for our purpose may be included among the fungi, are of great importance in maintaining soil fertility.

INJURIES FROM MISTLETOES

In addition to the fungi, true mistletoes and dwarf mistletoes cause serious plant diseases on many species of conifers and hardwoods in the United States. The true mistletoes are most abundant in the southern states upon broadleaf trees. The dwarf mistletoes in contrast are prevalent on certain conifers in the western United States (Gill 1935).

Very few if any of the important western conifers escape injury from dwarf mistletoes. They are particularly bad on ponderosa pine. This species suffers widespread damage from the dwarf mistletoes,

practically all the trees in some stands being infected. These plants anchor themselves upon their hosts and are evident externally and easily recognized. Though not true parasites, the mistletoes obtain water and some food materials from their hosts. The effect of mistletoes upon the host tree is at least to cause a reduction in growth and a decrease in the stocking of the stand. Often a witch's-broom effect is developed on individual trees. The entire tree may be killed if the mistletoes are numerous.

METHODS OF CONTROLLING FUNGI

Fungi cannot be kept under control by fostering their enemies, for practically none exist. Against most species of fungi attacking forest trees, direct action is impracticable owing to the expense involved and to the fact that the vulnerable parts of many fungi are hidden inside the hosts. Under ordinary circumstances indirect methods must be used in preventing the inception of tree diseases and in controlling those already started.

In forest nurseries the concentration of millions of young trees on small areas, with high money values per acre, enables the forester to afford direct control of fungi attacking the young plants. As soon as the necessary knowledge concerning the life history of fungi attacking nursery stock is known, control should prove practicable. Sometimes moving to a new nursery site or discontinuing the growing of a given species may be necessary.

The damping-off fungi are controlled directly by the application of various chemicals, either in solution or as dusts, which act to disinfect the soil or render it more acid. The chemicals are usually applied before the seeds are sown although sometimes treatment is given after the seedlings are up. The best chemical to use is not the same in all forest nurseries but must be learned by experience. Sulphuric acid, Bordeaux mixture, formaldehyde, and aluminum sulphate are some of the chemicals which are effective against damping-off. Various needle diseases of coniferous nursery stock may be controlled by means of chemical sprays.

Outside of forest nurseries very little direct control work should be attempted and results should be secured through indirect methods involving relatively small expense. The first step is to have a forest pathologist work out the life history of the fungus, provided this has not already been done. After the life history is known, practical steps to minimize the danger from the fungus can often be found and put

into effect. The work done by Hansbrough (1936) on the tympanis canker of red pine will serve as an illustration. This canker when discovered in 1932 had killed single trees and small groups of trees in red pine plantations. Investigation proved the fungus to be ordinarily saprophytic in habit but owing to drought conditions and too great a density of the stand it had temporarily become parasitic on the trees weakened by the shortage of soil moisture. The remedy advised was reduction of density by thinnings especially on the sites most subject to drought injury.

Silvicultural measures for general use should be directed toward keeping the stands in a thrifty condition since trees in full vigor have the best chance of escaping attack by diseases. In substance this simply means the practice of good silviculture. Among the measures particularly recommended is the prevention of forest fires because of the part which fire scars play in affording points of entrance for fungi. An exception may be found to the complete exclusion of fire from an area where fire used under controlled conditions may have a beneficial effect in checking the fungus, for example, the brown-spot needle disease on longleaf pine.

Other silvicultural measures include the systematic use of thinnings, the avoidance of wounding trees in logging or at other times, and the elimination of all infected trees, even if unmerchantable, when cuttings are made. In making thinnings in young and middle-aged stands containing trees of sprout origin, the question frequently comes up whether some of the individuals in a sprout clump can be safely cut, because of the danger that decay may enter the heartwood of the cut stub and thus pass into the remaining stems of the clump. As a general rule, stems 3 inches or less in diameter contain little or no heartwood and if cut low should heal over before decay develops. Stems more than 3 inches in diameter offer a greater hazard, particularly where the union between members of the sprout clump is so high above the ground that direct connection exists between the heartwood of the several stems. All stems having high unions should be cut or all should be left. Where the union is low and consequently no aboveground connection occurs between the individual stems some may safely be cut and others left (Roth and Sleeth 1939). The age of a stand and the relative resistance to decay fungi of the species involved may warrant modifying this treatment.

A sanitation clause often is included in timber-sale contracts on the national forests. This clause in substance provides that trees infected with disease shall be felled and so disposed of as to prevent their con-

tinuing as a menace to other trees. In theory it would be desirable to extend this work over all the forest area, thereby disposing promptly of all infected trees, rather than restricting such disposal to trees on timber-sale areas. Where a supply of labor as furnished during the existence of the former Civilian Conservation Corps is available this line of activity may be undertaken. Elsewhere the nature of the infection and the gains to be expected from the immediate removal of infected trees must be carefully considered before the work is attempted. Ordinarily the removal of infected trees can be justified under present economic conditions only on timber-sale areas where the return from the stumpage encourages a small investment for sanitation.

Hepting (1933) advises that in eastern hardwood stands, where trees bearing sporophores of heart-rot fungi are felled in sanitation operations, the sporophores be knocked off the felled trees; otherwise they will continue as a source of infection to other trees.

Sanitation cutting is the best method of controlling the canker diseases such as *Nectria* and *Strumella*. The best method of treating trees attacked by *Nectria* canker is to use them for cordwood and burn the remaining slash. If this is impracticable either girdling or felling will assist in reducing spore production (Spaulding, Grant, and Ayers 1936). *Strumella* cankered trees should be felled but not necessarily removed or burned. They should not be girdled and left standing since the fungus will continue to fruit on the standing dead tree (Hepting 1933).

Pathologists have sometimes argued that naturally reproduced stands should be preferred to those established by planting, since the former are considered more secure against tree diseases than planted stands. This is particularly true when root rots are feared since planted trees are liable to injuries in planting which may encourage the development of root rots. How important this point really is remains to be investigated. The *Fomes* root rot is the most dangerous root disease which has been noted in various parts of America. This fungus has been found in stands both of natural and artificial origin. It had been a primary cause in killing old growth timber in the unevenaged natural stands of conifers in the mountains of California (Wagener and Cave 1946). In these stands the fungus apparently does not require either wounds or dead portions of the root system for entrance into uninfected roots. Fairly close contact in the soil between a sound root and an infected one is enough for passage of the disease. The disease spreads from an initial center, usually a snag or stump. Hepting and Downs

(1944) found the *Fomes* root rot in eastern white pine plantations at Biltmore, North Carolina. Here apparently the fungus entered through dead roots, and these dead roots seem to be associated with poor root arrangement which the authors say could probably be traced to poor planting. They found a larger amount of rot in thinned as contrasted to unthinned stands presumably originating from stumps cut in thinnings.

This brings up the question whether the *Fomes* root rot is worse in thinned than in unthinned stands. Experiences in Europe apparently are divided on this point, although the more general opinion is that thinning helps in keeping stands healthy and consequently in reducing the amount of injury from this fungus. It would seem that the very dense overstocked condition of the Biltmore plantations must have had a good deal to do with the amount of *Fomes* root rot in the thinned stands.

Miller (1943) in discussing the susceptibility of eastern redcedar to the *Fomes* root rot states that suppression of cedar by other species renders the tree susceptible to attack and that little loss may be anticipated if cedars on suitable sites are exposed to full sunlight.

Deep planting of some shallow-rooted species of which Norway spruce is an example often causes a new root system to be started near the surface of the ground and results in the death of the lower portions of the original roots. It is possible that dangerous root rots may thus be encouraged to attack the plantation while it is still very young.

A risk incurred in planted stands arises from the possibility that the seed used in growing the planted trees may have come from a region not sufficiently like the new location to make the planted trees fully acclimatized. Should this be true, the plantation may at some time in its long life be severely injured or destroyed by a fungus because of this weakness. The Scotch pine planted in the northeastern United States which is now threatened with attack by the Woodgate gall rust and other fungi illustrates this point (Hartley, Boyce, and others 1933).

It is therefore important from the pathological standpoint that only seed from suitable localities and of species native to the region be used in artificial regeneration. Unfortunately in much of the forest planting so far carried out in this country this rule has not been observed, owing partly to ignorance of the importance of this step and partly to the exigencies of the situation which often forced the using of seed and planting material at least suspected of being unsuitable. As time passes there will be less and less justification for failure to use the right species and seed from the right source.

Pathologically, mixed stands as contrasted to pure stands, and many-aged stands as contrasted to evenaged, are preferable for minimizing the danger from tree diseases. Mixtures of hardwoods and conifers are especially desirable, since the two groups are rarely attacked by the same fungi.

Where sporophores borne on standing infected trees are a source of spreading a disease that causes serious injury to young and middle-aged timber, such as the *Nectria* and *Strumella* cankers on hardwoods in the eastern United States, the removal of infected trees, both on areas where timber is being harvested and also generally throughout the forest, is a sanitation measure of primary importance. It is essential in intensive forestry if crops reasonably free from such diseases are to be grown.

One possible method of control, in theory at least, namely the development of strains of trees immune to the dangerous tree diseases, has as yet received little attention in connection with the production of forest tree crops. The length of time involved in producing even a single generation of trees and the practical difficulties of tracing and governing parentage offer almost insuperable obstacles to the breeding of immune strains of forest trees. However, over long periods of time something may be accomplished in this line, although it is questionable whether the new tree itself will not prove unusually susceptible to fungus attack as has happened in horticulture.

Control of Heart Rots

Damage on a large scale from the fungi causing heart rots can be prevented in the timber crops succeeding the present one by use of a rotation sufficiently short so that the decay-causing fungi do not have the opportunity to destroy more than a small percentage, if any, of the timber. The earliest age at which heart rots will cause appreciable loss in second growth timber is above the rotations which will ordinarily be used when forest crop production is undertaken. This will minimize without any expense whatever future damage from that dangerous group of heart rots which today are the most destructive fungi in virgin timber.

The question is pertinent whether active steps should be taken, when old timber badly infected with heart rots is cut, to prevent infection of the new crop. This might include not only the felling of all infected trees but also the treatment of the infected slash in such a manner as to prevent the production of sporophores. For this purpose the larger

pieces of slash, which are the only portions in which heart rots occur, might be charred by fire or be otherwise so treated as to insure their drying out and thus check the development of the fungi. The results which may be secured from any special treatment of the larger pieces of slash, defective logs, and standing dead trees in lessening or preventing the production of sporophores by decay fungi do not justify the expenditures. A short rotation is so effective in eliminating serious losses from heart rots that the special treatment of slash should be unnecessary.

The retention for seeding purposes of trees not infected by fungi is in theory the wisest plan, particularly from the genetic standpoint. Since the life processes of the tree are not interfered with by heart rots, the necessity of leaving sound seed trees is not so urgent as in dealing with some other types of fungi. Practical considerations may outweigh the theoretical ones and justify the retention of trees affected by heart rots. This has been done in Douglas-fir stands in western Oregon and Washington.

Millions of acres of virgin timber still remain, principally in the western United States. Hence the problem of minimizing the loss from the heart-rot fungi now at work within the old trees of these stands is of importance. The trees which are still largely sound but rapidly becoming defective should be harvested if practicable, starting first with the stands which are decaying fastest. A stand of old defective timber may be making no net growth whatever and even be decreasing in volume each year. The greater the amount of cull material in the stand the more it needs treatment to remove or destroy the defective trees and enable healthy young trees to become established and occupy the area. Unfortunately, stands of defective timber usually cannot be logged except at a loss under the conditions of relative inaccessibility characteristic of virgin forest areas. Unless a present investment to make the forest productive can be justified, such areas will have to remain in their unproductive condition.

Control of Introduced Diseases

In dealing with diseases introduced from foreign countries and developing in epidemic fashion upon native forest trees, the question of possible control has to be carefully considered, and, if a practicable method of control is at hand, prompt action should be taken or wholesale destruction of the host may result. Up to the present time, two introduced diseases of the virulent type have ravaged certain of the

forests of the United States. These are the chestnut blight and the white pine blister rust. No method of combating the chestnut blight has proved practicable, and the disease may be said to have exterminated the American chestnut as a commercial tree. Impracticability of control is attributed to the favorable environmental conditions for the disease and to the fact that the life cycle of the fungus offered no loophole for cheap and effective attack.

Efforts to control the chestnut blight, involving large expenditures of money, although pursued for some years were ill-advised and finally were abandoned. The activity along this line is now directed toward developing a strain of chestnut possessing the resistant qualities of some foreign species of chestnut combined with the timber-producing qualities of the American chestnut.

On the other hand, the white pine blister rust, though finding an environment well suited for its development, is susceptible of control at a reasonable expenditure because of a weak link in its life cycle. This weakness is the fact that the disease has alternate hosts and cannot pass directly from one white pine to another white pine but must return to a *Ribes* (currants and gooseberries) bush before attacking an uninfected white pine. Control methods are applied to take advantage of this vulnerable point in the life cycle of the disease.

The white pine blister rust (Spaulding 1911), first introduced in America from Europe about 1900, is now distributed over the range of eastern and western white pines and sugar pine. Once the rust is established in a locality, the five-needled pines are subject to severe damage unless control measures are applied. The disease is susceptible of local control at expenditures that, for eastern white pine at least, make it possible to continue the profitable growing of this species over most of its commercial range. The western five-needled pines are more susceptible to infection than the eastern white pine and are associated with more *Ribes,* which are more difficult to eradicate than the eastern varieties. Control though more expensive than in the East should prove economically practicable on the areas best suited to western white pine, but probably not for sugar pine.

Control measures consist of the systematic removal of all species of *Ribes,* the alternate host plants of the disease. This prevents the disease from spreading to uninfected pine trees on the areas so treated. The *Ribes* should be removed not only from the pine area to be protected but also over a protection zone of varying width (up to 900 feet for white pine in the East) surrounding the pine area.

Three principal methods of *Ribes* eradication have been employed (Martin 1938; 1944):

1. Hand methods, which are used mainly in the eastern states and in upland types in the western states. The *Ribes* are either uprooted by pulling or by a suitable grubbing tool.

2. Spraying with chemicals (Offord et al. 1940). This has been used in the West on areas where there is a dense concentration of *Ribes,* making hand methods impractical. It has been applied where the bushes are very large with their roots located under rocks where they could not be hand pulled. The stream bottom land in the western white pine region is the principal place where chemicals have been employed. Mixtures of sodium chlorate and calcium chloride are applied in the form of a spray. The spray is put on with a back-pack hand pump. For destroying large bushes, the *Ribes* may be cut off at or below the ground level and a small quantity of liquid or dry chemical applied to the stump.

3. The third method may be termed the mechanical method. It is used only in the western states and ordinarily has been accomplished by a bulldozer fitted with a steel rake that clears the land of *Ribes* and brush. It is used only on areas where it is wished to permanently eliminate mixtures of brush and *Ribes.* The brush is finally burned and grass seed sown on the cleared area, which then becomes a meadow. The expense of clearing the land and sowing to grass should be returned over a 10-year period through sale of hay.

Following the initial removal of *Ribes,* the areas will need reeradication at intervals throughout the rotation approximately 5 years apart to remove *Ribes* that were missed in previous operations or that have originated from seed. The costs of these subsequent operations are materially lower than that of the original, since fewer bushes are found and since, generally, only a portion of the area needs attention.

In New England the average cost per acre (based on labor costs as of 1929) of the first three *Ribes* eradications will be in the neighborhood of 30, 15, and 10 cents per acre respectively (Perry 1929). These costs, including compound interest to the end of the rotation, represent an annual charge of only a few cents per acre per year for the actual area of pine protected. The cost will be higher for small areas of pine than for the larger holdings, because the zone cleared of *Ribes,* on the outside of the pine area, decreases in ratio to the pine area protected as the size of the latter increases.

In most eastern white pine areas, an allowance of 7 cents per acre per year for stands of pine 200 acres in size should be ample, with lower

figures for larger areas. In regions where blister rust is established, eradication of *Ribes* must be practiced as a regular operation in the growing of five-needled pines. As additional precautions against the blister rust, the white pines should be grown in dense stands (because the *Ribes* cannot thrive and spread under heavy canopy) and if planted should be set out only in localities where *Ribes* eradication can be carried on cheaply.

The effect of shade in slowing up or preventing the developing of *Ribes* bushes is being recognized in securing control of the disease. Foresters are urged to keep stands as close as possible, avoid heavy thinning, and reproduce by partial cutting. While from the standpoint of blister rust alone this may be good advice, it is questionable whether it can always be applied if the purpose of management is to continue to grow white pines. With both eastern white pine and western white pine, partial cuttings are likely to increase the percentage of other species and ultimately to cause the type to revert to something other than white pine. Certainly for eastern white pine the cost of *Ribes* eradication is sufficiently low so that areas can be kept reasonably free of *Ribes* and the pine stands properly thinned and reproduced in the manner most likely to secure good crops of pine. In the case of the western white pine the cost of eradication is much higher and there is a question as to whether on any but the best lands continuous growing of western white pine can be justified.

Wellner (1946) advises partial cutting methods for mature stands of western white pine, changing over from the customary method of leaving seed trees in this type. The latter method resulted in encouraging the growth of *Ribes* which had consequently an opportunity to infect the pine seedlings. The cutting of about 25 to 60 per cent of the merchantable timber is advised, leaving a thrifty stand which is removed in one or more cuts after the *Ribes* have been suppressed and adequate reproduction of white pine obtained. Wellner also advises in overmature stands and in less vigorous mature stands that all the merchantable material be logged and the slash, debris, and *Ribes* be disposed of by prescribed broadcast burning. Prescribed burning, in this case, consists of first a slow fire which consumes slash and kills the defective residual stand. Some of the *Ribes* seed stored in the soil is consumed, and the remainder germinates. Three to five years later the standing material on the area is felled and a second burn is run broadcast over the area, killing the *Ribes* bushes and any remaining *Ribes* seed in the soil. After this double burn, the area is planted to pine.

An illustration of the eradication of an introduced fungus is fur-

nished by the history of the larch canker in central and southern New England (Hahn and Ayers 1936). Reported in 1927 and probably introduced in 1904–1905, it is now considered eradicated. The reason for such complete success is attributed to the fact that larch is a scarce tree, principally found in plantations in the infected territory, plus the fact that, since this disease was believed to be a potential menace to Douglas-fir on the West Coast, sufficient funds for prompt eradication were easily secured.

Other diseases may in the future warrant similar measures of specialized control. Past experience with chestnut blight, white pine blister rust, and larch canker should be ample to indicate the advisability of a carefully enforced quarantine against the entrance of foreign plant material capable of introducing fungi new to this country.

METHODS OF CONTROLLING MISTLETOES

The cutting of infected trees is the only practicable method of controlling mistletoes, which spread easily and rapidly from tree to tree. In western conifer stands, the infected trees are continually spreading these parasitic plants. Until the advent of the Civilian Conservation Corps very little could be done toward removing mistletoe-infected trees, other than on timber-sale areas to cut those that were merchantable and fell the unmerchantable trees under the sanitation clause. Now that this corps has ceased to function, an additional supply of labor must be found before areas of young and middle-aged timber can be gone over and freed of mistletoe-infected trees.

Even when labor is available and the work appears economically justifiable complete eradication of the mistletoe is difficult, unless the infected area is clearcut. Some infections on apparently healthy trees are hard to find. In heavily infected stands the problem may be complicated by the necessity of leaving part of the stand to secure the establishment of reproduction. Where advance growth is established, all mistletoe-infected trees should be cut, if possible, before the advance growth is infected by the overstory trees.

THE FORESTER AS A PATHOLOGIST

The practicing forester should recognize the outward signs of attack by hidden fungi and be continuously on the watch for symptoms indicating a diseased condition of the trees. This does not mean that he needs to know each species of fungi, but he should be familiar with the

kind of injury caused by each of the various types and be able to recognize their presence in the forest. To determine the exact species causing the injury and to work out the life history and possible control measures for forest diseases as yet uninvestigated, a forest pathologist should be consulted. Ultimately a government service organization of experts trained both in forest pathology and in forestry should be provided to furnish just this type of assistance to the practicing forester and landowner. Assistance in fire protection, state- and nationwide in its application, is already furnished, and it is logical that a similar kind of aid should be provided in disease protection.

The help given by federal and state pathologists to private landowners in the eastern white pine region in eradicating *Ribes* illustrates the type of service which should be furnished for all pathological problems rather than for controlling one fungus alone.

In estimating standing timber it is necessary to determine the percentage of cull which must be deducted for timber decayed by heart rots. Timber cruisers and foresters have already become expert in recognizing the outward signs of hidden heart rots and are able to make reasonably accurate appraisals of the loss from this source to be expected when the timber is cut. Where old growth timber is still abundant, estimating cull may well be the most important pathological function of the forester and woodsman. However, as the old growth timber disappears, the relative importance of heart rots as compared to other types of fungi shrinks and the forester will need a broader knowledge in order to protect his second growth forest. The purposeful growing of forest crops will create and intentionally maintain forest conditions which, in contrast to the virgin forest, will favor the development and spread of many fungi other than heart rots.

The average forester today fails to appreciate how threatening a factor attacks by injurious plants may prove to be in the production of forest crops and how necessary for success it will be to adjust management practices to meet these attacks.

INJURIES FROM FOREST WEEDS

Forest weeds include various kinds of plants—herbs, shrubs, vines, and many tree species. They are all alike in one respect, namely, their position with reference to the desirable trees in the forest. This position is a dominating one. The forest weeds overtop the better tree species and threaten by their competition to stunt, deform, and kill them. All forest weeds are characterized by the ability to outgrow in

height, at least for a short period of time, the desirable crop trees with which they are associated. Thus, the forest weeds obtain a dominant position in the crown canopy early in life and so long as this position is retained exert injurious competition. Grass overtopping very young trees and inferior species like gray birch dominating eastern white pine are two examples of forest weeds. Such weeds are most numerous and threatening on rich soils and in tropical climates, where growth is extraordinarily rapid and the site is adapted for a large number of plants. Forest weeds, however, are found in the great majority of forest types.

As soon as crop production is taken up, this nearly universal and frequently important type of injury by plants demands recognition and the adoption of measures to secure the safety of the crop trees. The objective should be to prevent the forest weeds from obtaining a dominant place in the stand. If this can be accomplished the crop trees will be relieved of serious overhead competition and will develop unhampered by forest weeds.

When treatment is started too late to prevent the forest weeds from growing into a dominant position overtopping the crop trees, then the elimination of this competition should be undertaken as soon as it is discovered.

The encroachment of forest weeds upon the desirable trees frequently starts the very year that the new crop is established. Oftentimes such competition is hardly suspected, particularly when herbaceous plants, such as grasses, constitute the forest weeds. Grass competition may be very serious for the young crop starting underneath. Pearson (1934) found in the ponderosa pine forests of the Southwest, where certain grasses were abundant and luxuriant, that seedlings of ponderosa pine could not survive unless a large share of the overtopping grass competition was eliminated.

METHODS OF CONTROLLING FOREST WEEDS

Methods of preventing or controlling damage from forest weeds consist in killing or removing those plants which either are going to obtain or have already obtained a dominating position over the trees which it is intended to develop into the ultimate crop. A variety of methods exist for accomplishing this purpose. Cutting the forest weeds is the simplest and usually the method first tried. Such work often proves expensive unless the forest weeds have a sale value. Hence a cheaper method is sought. Modifications of the usual cutting method include

treatment of the forest weeds with applications of poison or by girdling the stems.

The effect of girdling is to cause the gradual death of the plant, thereby removing its competition. In order to be effective, the girdling must go through the bark and preferably well into the sapwood. Even though the plant may not die during the first season, the girdling results in a lessening of the competition and ordinarily in the death of the plant within 1 to 3 years. The details of applying the girdling method should be arranged to fit the species with which it is being employed. Girdling has an advantage over actual felling in that the overtopped trees are uncovered gradually and the damage from falling limbs is less than in felling. Girdling is adapted only for use in disposing of the larger forest weeds. Any stems less than 5 inches in diameter can be felled more cheaply than girdled.

Several methods of girdling are quite generally recognized (Westveld 1942) as follows:

Notching, in which a notched ring is cut around the tree through the bark and ½ to 2 inches deep into the wood.

Single-hacking, in which a single line of overlapping ax cuts is made completely around the tree. The cuts go through the bark and into the wood.

Double-hacking, in which a line of chips is removed completely around the tree by the process of striking two downward blows one about 3 inches above the other, thereby enabling a chip to be thrown or pried out.

Peeling, in which the bark is stripped off in a band at least 8 inches wide completely around the tree.

Notching is expensive but effective and should be used on trees difficult to girdle properly, such as those with infolding bark. Single-hacking is relatively cheap and if well done accomplishes the purpose of killing the trees, but careless work is difficult to discover until too late because no chips are thrown out. Double-hacking is likely to secure better results than single-hacking, if done by unskilled labor, and is easier than notching because the ax strokes are all downward rather than partly horizontal or upward. Peeling can be done very cheaply in the spring and early summer when bark strips off easily.

Peeling has a further advantage, when preventing the girdled trees from sprouting is important. This is sometimes, though not always, essential. Sprouting of girdled trees is made possible by the reserve food supply in the roots. If this food is allowed to pass up the tree into the crown, as it would be if the girdling is restricted to bark peeling,

sprouts will not be immediately developed below the girdle. Since no food can now pass downward from the crown to the roots, because a ring of bark has been peeled, the roots get no more food and finally die. Their death is followed by the death of the top.

Sometimes poisoning will prove more effective than either girdling or felling. A ring of incisions is cut around the stem, and the poison solution is introduced through these cuts into the sapwood. It is not necessary that the cuts join entirely around the stem, but they should not have gaps between them of more than 1 or 2 inches. The cutting is done usually with an ax or hatchet, although a special tool has been devised by Cope and Spaeth (1931) for the purpose of applying poison solution to the tree.

Pessin (1942) developed a method of placing sodium arsenite in holes bored or punched in the stem or roots of the tree with a special patented punch mounted on an ax head. One hole is enough for a 3-inch tree and two for a 5-inch tree. The holes are filled with sodium arsenite solution, which is soon absorbed by the tree with little chance for animals to be poisoned. The cost was estimated at less than 1 cent per tree. The method is advised for killing small oaks 2 to 4 inches in diameter overtopping longleaf pine.

The choice between poisoning and girdling will often be made on the basis of the relative freedom from sprouts arising from the roots of the treated forest weeds. Apparently, all species do not respond in the same way to girdling and poisoning operations. Sometimes, but not invariably, poisoning proves efficient in preventing resprouting. The season of the year also may affect the extent of sprouting.

Though poisoning has already proved an effective method, it has not as yet been employed so extensively as felling and girdling for killing undesirable trees. One reason for this is the danger to the operators in handling the poison and the probability of killing domestic animals and wildlife. Another objection is the cost which in many cases is higher than for girdling. If Pessin's method proves as cheap and effective in other forest types as in longleaf pine, the use of poisoning is likely to be increased. Poisoning has the same advantage as girdling in that the dead trees go to pieces slowly and cause very little injury to the released trees.

Where the competing forest weeds are of small size and palatable to animals their elimination as serious competitors of the desired crop trees sometimes may be accomplished without expense by admitting livestock to the area. The livestock are expected to eat the grass and other palatable forest weeds and leave the crop trees not only uninjured

but freed of the overtopping weeds. This method is of value only if the animals prefer to browse upon the forest weeds instead of upon the crop trees which need release. In the rare case where the species to be released from forest weeds is as fire-resistant as longleaf pine, a controlled fire may be run over the area killing the weed species but not harming the favored species.

The operation of treating forest weeds overtopping crop trees is known in silviculture as a cleaning, weeding, or release cutting. This is a well-recognized and necessary cultural operation in all intensive forest management and is best considered in full detail when studying silviculture. The object of discussing the operation here is to emphasize its importance from the forest protection viewpoint.

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CHAPTER 16

Protection against Insects

EXTENT OF THE DAMAGE

The annual loss caused by insect depredations is more difficult to estimate accurately than the fire loss, because for fires statistics (incomplete to be sure) are gathered by nearly all forestry organizations whereas there are no detailed records of losses caused by insects. General estimates made by entomologists on the basis of observation and consultation with other experts furnish the best available information. Figures issued by the U. S. Forest Service (Anonymous 1946) indicate that insects, disease, and wind combined (with some other minor destructive agents included) cause a drain on the forest more than twice as large as that caused by fire. It may be that annual destruction caused by either insects or disease is in excess of the annual damage by fire.

This situation will continue in the United States certainly as long as there remain extensive bodies of virgin timber because of the great susceptibility of mature and overmature stands to insect attack. Spectacular losses from insects occur today in areas of virgin timber located in inaccessible regions where timber of high quality is killed without the possibility of salvage. After the virgin timber has disappeared, insects will still remain a major source of injury to forest crops, for second growth timber is attacked by many serious insect pests. From the practical standpoint, a much larger proportion of the annual damage caused by insects is unpreventable than of that caused by forest fires. Insect depredations cannot be so directly and completely prevented as forest fires.

CHARACTER OF THE INJURY

Insect depredations range from slight injuries to single trees up to the killing of a large proportion of the timber over extensive regions. Insects may deform, weaken, or kill single trees or cause a reduction in the growth rate. The killing of many trees on a given area is easily observed. Damage to single trees and small groups of timber often goes unnoticed, although in the aggregate it must reach a tremendous total and may exceed the loss in the large outbreaks.

There is always an insect population in the forest continually causing some injury which may be termed the normal amount of damage for the given insect. This represents the endemic stage of insect injury. At certain times the normal population of a given insect multiplies enormously. Consequently the damage is increased on the areas affected and the insect is considered in the epidemic stage. Injury from these insect epidemics or outbreaks occurs periodically at irregular intervals whereas the endemic or normal attacks are of annual recurrence.

Some insects cause serious damage only when in the epidemic stage; other insects, owing to the type of injury which they inflict even when present in small numbers, may always be a source of significant damage. For example, one small brood of the white pine weevil working in the terminal shoot is likely to cause a serious crook in the main stem of the tree. This class of injury may be expected year after year even though the insect may never increase in numbers to an epidemic stage. In contrast, the gypsy moth may be present year after year in a forest eating the foliage, thereby weakening the trees and reducing the growth rate, but until this insect builds up sufficiently in numbers to reach an epidemic stage and cause abnormal stripping of foliage the damage is overlooked. Thus, no attention is paid to the damage done by many insects except when periodically they attain epidemic proportions, whereas the annual more or less normal, endemic damage of many other insects actually is a matter of serious concern each year.

In no part of its life cycle is the tree free from insect enemies. The seed even while it still remains upon the mother tree may be destroyed by insects. After germination of the seed, the young trees are exposed throughout life to a succession of insects each suited to the size and condition of the tree. A cutworm, for example, may kill a tender young seedling but not a 50-year-old tree. Some species of insects prefer or are restricted in their attack to trees of a certain age, either preying

upon young reproduction, upon saplings and poles, or upon mature individuals. On the other hand some insects, such as defoliators, may feed on trees of all ages.

Where small seedlings of a single kind are concentrated by the million in limited space, as in forest nurseries, the damage by certain types of insect enemies may develop on a wholesale scale. Natural reproduction starting on cutover areas is often seriously injured. In stands approaching maturity outbreaks are likely to develop which may destroy the whole stand. Such outbreaks are not confined entirely to old timber, but, because stands particularly those in the unmanaged forest decline in vigor with advancing age, certain types of insects such as bark beetles are able to build up to epidemic stages more readily than in middle-aged and young timber. As far as defoliating insects are concerned it is more a question of abundant foliage than of a weakened vigor of the tree, and epidemics may build up in relatively young stands. On the whole, stands from the reproduction stage until early middle age suffer less from insects than those younger or older.

Insect outbreaks in American forests have so far been of more common occurrence and of more serious consequence in coniferous than in hardwood forests. Pure stands of conifers are particularly susceptible. Conifers do not recover so easily from insect injuries as do hardwoods, because hardwoods contain greater reserve stores of food and replace injured parts more readily. As an illustration, complete defoliation by the gypsy moth ordinarily causes the death of a conifer, whereas a hardwood tree may survive several defoliations.

Every part of the tree including the roots, buds, seed, leaves, cambium, bark, sapwood, and heartwood has its own particular insect enemies. Each species of tree may be attacked by distinct species of insects, although most insects attack more than one tree species.

The injury inflicted may be of a physiological or of a technical nature. Under the former come injuries such as defoliation, deformation, sap sucking, and girdling, which interfere directly with the physiological life processes of the tree; under the latter are included injuries such as those by wood-boring insects, which may ruin or reduce the value of the tree for commercial products but which do not interfere directly with its growth.

The killing of trees by insects increases the amount of inflammable material in the forest and makes the forest more open. Both these points tend to increase the fire danger. Insect epidemics are often followed by disastrous fires made possible by the fuel in the insect-killed trees.

Conversely, fires injuring the standing timber are likely to be followed by a larger amount of loss from insects than occurred before the fire. This may be explained by the fact that the vitality of trees damaged but not killed by the fire has been reduced, and sometimes both the sapwood and heartwood of injured but still living trees have been exposed. The entrance of insects through the fire scars and as a result of the weakened condition of the trees often occurs shortly after a fire. The fire frequently exerts an attractive influence for insects in the neighborhood. But though they may come to the fire-injured trees in large numbers they may not always find conditions suitable for development and may perish in their new environment.

The opening of the forest through the killing of trees by insects usually results in understocked stands and decreased growth per acre. It is possible that the loss of insect-killed trees will act as an excellent thinning, increasing the growth of the remaining stand. Although this possibility is recognized the chances are against obtaining exactly the right degree of opening as a result of insect attacks.

Insects frequently make possible the introduction of fungi into previously sound trees. This may be done by the insect directly in carrying the fungus to the tree, or the holes left by insects may afford openings through which infection by fungi occurs. Some of the scale insects and boring insects are the ones most likely to assist in the spread of fungi.

INSECTS RESPONSIBLE FOR THE DAMAGE

Leaf eaters and boring insects constitute the two most destructive classes of forest insects. Among boring insects the bark beetles of the genus *Dendroctonus* are of particular importance. In the western half of the United States the prevailing coniferous forests of virgin timber suffer their greatest insect losses from the ravages of these bark beetles. In regions of second growth timber the bark beetles may be relatively less injurious than other insects, especially the defoliators. In the forests of red spruce and balsam fir in the northeastern states, the spruce budworm, a defoliator, is far more dangerous than bark beetles. As the virgin timber is exhausted and is replaced by second growth, the leaf eaters are likely to occupy the primary place as insect enemies of the forest.

Even in the virgin forest leaf-eating insects may assume threatening proportions. An outbreak of the pandora moth, a dangerous defoliator of ponderosa pine, is reported to have extended over 400,000 acres of

virgin forest in southern Oregon between 1918 and 1925 (Anonymous 1933, p. 724). Growth was reduced approximately 32 per cent as a result of the epidemic. The forest is made more susceptible to attack of bark beetles as a result of defoliation.

Various systems of classifying forest insects have been proposed. Graham (1939), basing his classification to considerable extent upon part of the tree attacked and method of attack, divides forest insects into:

1. Leaf-eating or defoliating insects which devour the foliage.
2. Insects feeding upon the meristematic tissues, which include the cambium layer, the growing tips, and the adjacent soft portions of the xylem and phloem. These tissues are rich in protein and afford palatable food to many species. Graham recognizes three groups of such insects, namely, (1) those feeding on the terminal parts of trees including twigs and roots, (2) insects working in the cambium region of the trunk and branches (the important group of bark beetles falls into that class), and (3) those attacking both cambium and wood.
3. Sap-sucking insects. These insects obtain their food by sucking the sap from trees. They are serious pests principally on nursery stock and in young stands.
4. Wood destroyers (principally secondary * insects on forest products rather than on standing green timber).

In addition to the four classes of insects attacking trees there are two other classes which attack insects and so far as they attack injurious insects are of importance in forest insect control. These two classes are: (1) parasites or insects which for a part of their life cycle live in or on one individual insect and gradually consume it, and (2) predators or insects which kill many individual insects.

Forest insects may be classed as injurious, beneficial, or neutral. The beneficial insects function either as parasites or as predators. Neutral insects are those present in the forest which have no distinctly beneficial or injurious influence.

It is outside the scope of this book and unnecessary for the purpose at hand to describe here or even to list the species of insects affecting forest trees. For detailed lists and descriptions of injurious and beneficial insects, the literature treating forest insects should be consulted. For this the reader is referred to Craighead and Middleton (1930), Doane, Van Dyke, Chamberlain, and Burke (1936), and Graham (1939). Under the methods of control, considered in a later part of the

* Secondary insects are those which cannot attack and normally develop in a healthy tree in contrast to primary insects which can do so.

chapter, a few examples of specific insects are discussed in order to illustrate the type of methods practicable in controlling the more important classes of insects.

CAUSES OF INSECT ATTACKS

Insects attack trees merely to obtain food, for example the leaf eaters, or to secure food and places in which to breed, for example certain bark beetles and wood-destroying insects. The need for food is the underlying cause of insect attack upon the forest. Man's attention has been called to the forest insects only because of the awakening interest in forest crop production, largely developed during the last four decades. However, forest insects have been in need of food for many centuries and indeed have been present and active presumably as long as forests have existed. Certainly insect attacks on a large scale are not of recent origin, for there is evidence of widespread destruction in the past.

The climax forest has sometimes been thought of as having a stable equilibrium, the forest being maintained indefinitely in its existing character. This concept is not borne out when the virgin forest is investigated. A stable equilibrium has not been maintained at all times, but on the other hand the composition and form of the forest often have changed appreciably over a period of several hundred years. Natural catastrophes and the actions of early men were the principal contributors to this lack of stability. Undoubtedly the forest insects rose and fell in numbers as a result of the changes in the forest, and they undoubtedly contributed significantly in effecting some changes.

Today the influence of man overshadows the importance of natural catastrophes in changing and controlling the character of the forest. Man is now starting to produce forest crops, and a situation with respect to forest insects and forest crops somewhat similar to that already existing with respect to agricultural crops and insects will develop.

The experience in agriculture and in forest crop production in Europe, as well as limited instances in this country, indicates that, with the violent changes from the wild unmanaged forest caused by harvesting timber and carrying on cultural operations, new conditions favorable for the multiplication of one or more injurious insects will be created. This cannot be helped if desirable forest crops are to be grown and harvested, even though the extent and nature of the changes from the original forest is minimized.

Under normal conditions an insect will be found occurring in relatively small numbers, attacking single trees or small groups of trees here and there throughout the forest. When for some reason conditions become particularly favorable for rapid multiplication, the insects will increase enormously in numbers and extend their ravages.

Unquestionably forestry operations will in the future be a cause of many incipient insect outbreaks. But it is doubtful that they can result in destruction any greater than has been experienced in unmanaged virgin forest. Control measures, it is hoped, will prevent these incipient outbreaks from becoming actualities. One of the effects of logging operations and forestry practice in the United States has been to create more pure stands than previously existed. Since pure stands imply the concentration of a large supply of one kind of food, they offer an unusual opportunity for the rapid increase of an insect partial to that particular food. This undoubtedly has been an important cause in some places for increased insect activity. On the other hand, plenty of food is supplied in many mixed stands for the development of a serious outbreak.

Insects, just the same as trees, have climatic requirements for their optimum development and also for their existence. Climate limits the distribution of insects. Inside the climatic zone embracing the range of an insect, its seasonal and regional development will be influenced principally by fluctuating temperature and moisture conditions. Temperature and moisture exert upon the insect not only a direct influence but also an indirect influence through affecting the health of the trees favorably or unfavorably. For example, a drought weakens the trees and hence they succumb more readily to insect attacks which would not prove serious on vigorous individuals.

The requirements for heat and moisture are not the same for all insects. An increase in humidity or in rainfall may favor the development of some insects but inhibit that of others. Each insect has temperature limits below and above which its activities are curtailed and death ensues. On the whole, more species of insects occur in warm climates and at low elevations than at high altitudes and in cold climates.

In general, favorable weather conditions and an abundant supply of the insect's preferred food, together with a low population of the insect's parasites, are the principal causes leading to development of an insect outbreak.

METHODS OF CONTROL

The ever-present danger of serious losses from insect depredations justifies the development of a systematic plan for the prevention of injury and the control of insect outbreaks. Eventually it will be recognized that protection from insects merits as careful consideration as protection against fire. Prevention of insect outbreaks and reduction of the endemic losses to the absolute minimum are the goals sought. As with fire protection, prevention of a serious attack is always preferable to control of an outbreak once started. Direct control should be resorted to only as a final effort.

As a starting point, full information is needed in regard to the insect: its life history, food preferences, natural enemies, and frequency and causes of outbreaks. This knowledge may reveal some weak point in the life cycle of the insect, and it is essential in planning control measures.

The damage from forest insects can never be entirely prevented. Countless species of insects live in and feed upon the forest. A large share of them exist without the forester's being aware of their presence or of the damage caused. Most of these insects never develop into real forest pests and must ordinarily be disregarded in plans for insect control. It is impracticable to attempt control of the damage caused by these minor insect enemies of the forest. A relatively small number of insects constitute the list of serious forest pests whose ravages must be controlled.

The intensive methods of prevention and control possible in the protection of shade and orchard trees cannot be applied to forest crops, because of the high cost in relation to the value of the resource threatened. Even in the forest much can be done, largely through indirect methods, in the way of preventing outbreaks of the serious forest insect pests. Eventually a large share of the loss due to insect outbreaks can be prevented without appreciable extra cost by proper forest management. The principle of spending a large amount per acre on a small area may be justified, provided the expenditure insures safety for a long enough time over sufficiently large adjoining areas.

The complete extermination of an injurious insect is practically impossible. Since dangerous insects are always present, the primary objective should be to prevent their increase to dangerous numbers. In many forest types this objective can be attained through proper forest management. Occasionally such favorable natural conditions for rapid

multiplication of an insect occur that this insect reaches an epidemic stage in spite of forest management. This occurs most frequently in relatively inaccessible regions where forest management cannot be intensively applied.

Where outbreaks are likely to occur in spite of proper forest management, special control measures to keep down the insect population may be justified if the results to be gained warrant the expense.

Some forest insect pests require control chiefly to keep them from building up into the epidemic stage, as for example the spruce budworm, while other dangerous insects, like the pales weevil and the locust borer, require control not so much to prevent development to an epidemic stage as to minimize the endemic damage which occurs more or less regularly year after year.

The methods of control admit of classification in various ways. For the purposes of this discussion they have been summarized under six headings, each of which is treated separately in the succeeding pages. The headings more or less interlock and overlap, certain types of control work being susceptible of classification under more than one of the main headings.

Control by Natural Enemies

The natural enemies of injurious forest insects include parasitic and predaceous insects, birds, certain mammals, and diseases of various types which destroy injurious insects.

Undoubtedly, natural enemies are one of the chief factors in controlling the numbers of injurious insects. Natural enemies keep many insects continually in check until a disturbance of the existing biological relationships through cuttings or other factors weakens their beneficial influence. The practical point of interest to the forester is how the beneficial influence of natural enemies upon forest insects can be maintained and increased. The most obvious way would be to augment the numbers of the natural enemies by introduction of new colonies. This has been done occasionally by introducing certain insectivorous parasites and predators, particularly those of the gypsy moth and of the European spruce sawfly, but it is an expensive method and not always practicable. It finds its chief justification in connection with foreign insect pests which have become established in this country but for which adequate parasitic and predaceous insect enemies are lacking. Complications may occur when new predaceous insects are intro-

duced, for they may attack native beneficial insects as well as the injurious insect they were brought in to destroy.

The calosoma beetle is an example of a predator which has been introduced and successfully established in the gypsy-moth territory in New England by the U. S. Bureau of Entomology and Plant Quarantine, which for many years maintained laboratories in this territory for rearing parasites and predators of the gypsy moth (Burgess and Collins 1915).

The Canadian government has established a laboratory to breed insectivorous parasites for controlling the European spruce sawfly, a foreign insect introduced probably several decades ago (Mulloy 1936). This insect has developed to dangerous proportions within recent years and has done enormous damage to the spruce forests in eastern Canada and the northeastern United States. Control of insect pests by their natural enemies, though continuously in operation, is, with occasional exceptions such as noted above where new parasites and predators can be introduced, a matter not susceptible of much concrete action at the present time. The natural enemies of insect pests, particularly the birds, should be protected at all times.

Natural enemies of injurious insects, if dependent for their chief food supply upon such insects, increase in numbers as the population of the injurious insect builds up. Eventually the natural enemy may gain the upper hand and be primarily instrumental in reducing the injurious insect to normal abundance. This, however, does not prevent the injurious insect from reaching an epidemic stage. In other cases the natural enemies may be continuously so effective that no outbreak can develop.

Beneficial insects, both parasites and predators, are likely to be the most effective single natural enemy. Insect diseases, such as the wilt disease of the gypsy moth (Reiff 1911), may suddenly destroy vast numbers of insects; but such diseases become virulent only when the insect numbers have increased to an enormous total. Hence diseases do not check insect outbreaks until extensive injury has taken place. Birds may be effective in preventing the start of an outbreak but will be too few in number to cope with a serious outbreak once it has started.

The natural enemies of injurious insects cannot be depended upon under all circumstances to prevent the development of serious insect infestations. Other methods in which the forester can take a more active part must also be employed. Nevertheless the assistance which natural enemies furnish in reducing the population of injurious insects should not be overlooked.

Control by Treatment of Infested Trees or Portions of Trees

The principle involved in this method of treatment consists in so treating trees or their portions, such as stumps, logs, or tops, which are infested by insects as to interrupt the normal life cycle of the insects and destroy them. Sometimes the trees and portions in which infestation is expected may be treated before the insects have entered and such an unfavorable environment be created that the insects cannot live there. A large variety of work suitable for controlling different types of insects is possible under this method of treatment.

Bark-Beetle Control. The treatment of standing trees infested with bark beetles (particularly species of *Dendroctonus*) may be necessary in old growth stands of conifers especially the pines and spruces. Where the timber is accessible and of merchantable quality the problem can be solved by felling and utilizing the infested trees. If utilized in or near the forest the unutilized parts of the logs such as the slabs and bark must be burned.

The season for the operation must be chosen so that the trees are cut and removed from the forest and the unutilized portions burned before the insects emerge from the trees or logs. When river driving is in use or where water-storage facilities exist adequate for the amount of timber to be treated, the logs after cutting can be put in water for several weeks until the insects are either killed or the logs floated out of the forested territory.

This method of cutting while the insects are in the trees, coupled with either prompt utilization and burning of the refuse, or with storage in water, is the most practicable method to employ for controlling bark beetles wherever the timber is marketable. It will be used more and more as timber growing gets under way on a big scale. As a matter of fact, since most species of bark beetles find the best conditions for development in overmature timber, the application of forest management, involving as it does the harvesting of such timber first, will go a long way toward permanently decreasing the ravages of these insects in coniferous timber.

Unfortunately, today there are still forest areas in the western United States stocked with overmature timber which cannot be utilized profitably at the present time but in which attacks of bark beetles are a constant menace. Here various other methods of treating infested trees have been developed, and they may still find application until economic conditions improve enough to permit the commercial utiliza-

tion of infested timber. The details of treatment for the standing trees attacked by bark beetles must be worked out scientifically to meet the circumstances of each individual infestation. Frequently the affected trees are felled and the bark peeled from a large portion of the trunk and burned in such a way as to destroy all the bark beetles (Keen 1939, p. 186).

Felling and peeling trees and burning the bark are relatively expensive, and in the search for cheaper methods the U. S. Bureau of Entomology and Plant Quarantine developed a method of burning the bark with oil. This may be applied either to standing or felled trees and is particularly useful on thin-barked trees like lodgepole pine. When standing trees are burned the oil is sprayed on the bole of the tree and then the tree is fired at the base. The fire creates sufficient heat to kill the beetles as well as the tree. With tall trees it is often impracticable to spray oil up high enough so that the entire infested length of trunk is run over by a fire sufficiently hot to kill the beetles. Such trees must be felled and the infested length cut free from the top. A fire is then started at the base of the trunk and by means of spraying oil along one side of the trunk and down the other side the fire is carried up and back the length of the trunk. The trunk is then given a quarter turn and the unburned sides are treated similarly. Fuel oil is customarily used for this purpose and is applied on either the standing or felled trees by means of a 5-gallon back-pack pump of the type employed for firefighting.

On felled trees the amount of oil applied can be increased easily to such amounts that the heat generated by the fire will be sufficient to kill the beetles in thick-barked species of trees.

Another way of killing the bark beetles in infested trees is to fell and limb them and leave the trunk in a position exposed to the heat of the sun. After a few days' exposure to the sun the tree trunks may be rolled over so as to turn the other side of the trunk to the sun, thus creating unfavorable conditions for the bark beetles throughout the trunk. In this method, temperatures inside the bark are raised by solar heat to the point (115° to 120° F.) necessary to kill the insects. A variation of this method consists in peeling the bark from the felled tree and laying it in open spots so placed that the sun will heat it.

Even where most efficient and cheap methods are employed, the cost of treating infested trees of no present sale value represents an investment that may amount to several dollars per acre. Can it be justified? The argument for such treatment is based on the theory that if seriously infested trees are treated outbreaks can be avoided and the loss

of a large portion of the stand prevented by a relatively small expenditure. The standing timber though unsalable today may have value later on. The probability of its attaining such value in excess of the cost of protection should have influence in deciding for or against the treatment of infested trees. If infested trees are taken out each year, when few in number, by the regular forest staff, the ultimate costs might be kept within more reasonable limits than if treatment of infested trees for bark beetles is applied only periodically and when an outbreak threatens. If timber will soon be salable there is more justification for a larger expenditure to save it than if salability is likely to be a matter of 3 or 4 decades and a relatively large expenditure may have to be repeated several times.

Where economic conditions make possible small scattered logging operations, the expense of treating infested trees can be avoided and such trees can be taken out of the woods and utilized without expense and usually at a profit. This creates an ideal situation for the prevention or control of an outbreak. In many forest regions such good market conditions do not prevail. Hence it becomes a question of whether in the given instance money should be spent to cut and treat infested trees.

Considerable sums have been spent by the U. S. Government and by private landowners in fighting bark beetles, particularly in virgin forests of ponderosa pine and other conifers. The results have not been uniform. Control has been attempted for seven species of bark beetles, each species presenting a different problem in various forest types and regions requiring variation in the methods for each species (Anonymous 1933). With some bark beetles preventing or controlling an outbreak by treatment of infested trees appears feasible. With others, climatic and environmental conditions affecting the resistance of the timber and the vigor of the beetles apparently are the controlling factors, which can be only slightly changed by treatment of infested trees.

One of the most dangerous bark beetles in this country is the southern pine beetle. It can attack not only mature timber but also second growth stands, and may kill a large proportion of the stand (Craighead 1925). Heavy rain is unfavorable for the insect and may stop outbreaks, but the long, warm growing season in the South is favorable. As yet, adequate control methods have not been worked out.

Treatment of Slash and Stumps. The slash and stumps left after logging afford breeding places for many insects, and the necessity of treatment to prevent injury to the remaining stand must be consid-

ered. Insects capable of killing living trees breed chiefly in the larger portions of the trunk but do not always find conditions ideal for their development in the large tops and cull logs. Fewer insects may emerge from the slash than enter it.

Where utilization is close and the timber is sound and straight, the only part of the tree of large diameter which remains after logging is the stump or portions broken in felling. Where timber is rotten or crooked, cull logs or butted-off portions may be left. These discarded logs may be more of a menace than the limbs and tops of the tree. However, in general, slash is not considered such an insect hazard to living timber as to warrant disposal.

The cutting operation itself undoubtedly attracts insects, of which the most dangerous are bark beetles, and they may attack living timber near by. Attraction of insects to the neighborhood cannot be remedied by any method of slash disposal. From the entomological standpoint it is not worth while, except in rare instances, to apply any of the ordinary methods of slash disposal which are intended to dispose principally of the material 4 inches or less in diameter. If cull logs are an insect menace on any particular area they may be peeled, burned, or given some other special treatment. Where the risk from bark beetles is considerable windfalls should be disposed of, as their presence increases the chances for an outbreak.

Stumps might be peeled or sprayed and burned with oil if they constitute a menace. Such an expense is not commonly justified.

Treatment for Tip- and Root-Feeding Insects. When branches or terminal shoots of young trees are attacked by boring insects it may sometimes, though not always, be a practicable measure to control such insects by cutting off and burning the injured portions. The white pine weevil which attacks the terminal shoots of eastern white pine is an example.

The white pine weevil is a major insect pest of eastern white pine, and various methods of control have been advocated. These will be discussed under the heading Control by Forest Management. In regions where eastern white pine is not particularly abundant the method of cutting off and burning infested tips in young stands, particularly plantations, is effective and less expensive than other methods of control which might be used. In such regions the individual stands are more or less isolated so that infestation from adjoining territory is a minor factor. The removal of the attacked tips makes an appreciable reduction in the amount of infestation in the treated stand. This

reduction is not offset by prompt reinfestation because of the scarcity of pine stands.

Root-feeding insects cannot be controlled except in the nursery. The principal insects attacking tree roots in forest nurseries are the white grubs or May beetles. Control of these grubs is discussed on page 233.

Control by Application of Chemicals

Against certain types of insects chemicals as sprays, fine dusts, or fumigants are employed on a large scale in agriculture and in protecting park and shade trees. Spraying or dusting forest crops with poisonous chemicals, although practiced on a limited scale for some time, has only recently been developed along lines which promise to make the use of chemicals a practicable control method in the forest. On large tracts the sprays and dusts can best be applied from aircraft. On small areas with a close network of wood roads passable by trucks the chemicals may be applied by power equipment mounted on a truck. The use of DDT applied usually as an oil solution (5 per cent) at the rate of 1 spray-gallon per acre in the form of a fine mist may do much to cheapen the cost of chemical treatment. Already forest areas have been treated at costs of less than 1 dollar per acre.

The results of spraying by airplane with DDT solutions for gypsy moth control by the Bureau of Entomology and Plant Quarantine in infested woodlands in mountainous areas of New York and Pennsylvania during 1946 have been summarized by Sheals (1947). Among other points of interest, he states that this control was done at a cost of slightly less than \$1.50 per acre on approximately 100 square miles treated in contrast to the previous cost ranging from \$15 to \$25 per acre when lead arsenate was used with the conventional type of ground spraying machines. Similarly, Bodine (1947) states that, during 1947, outbreaks of the fir tussock moth on 400,000 acres in northern Idaho were controlled by airplane spraying with DDT solutions at an average cost of \$1.75 per acre.

Aside from the cost of using chemicals, their effect upon other life in the forest must receive consideration before poisoning methods for protecting forest crops are introduced on a large scale. If possible, a concentration of the chemicals adequate to kill the insects but not powerful enough to destroy other life should be applied.

Another method of using chemicals to combat bark beetles is described by Bedard (1938). The method consists in injecting certain toxic solutions into the tree. The bark is removed in a band around

the tree, and a collar of rubber sheeting is fastened over the peeled band. The poison solution is poured inside the collar, and gradually it enters the water-carrying vessels of the tree. Copper sulphate is considered the best chemical for injection because of low cost, effectiveness, and ease of handling. Excellent results have been secured in treating western white pine infected with the mountain pine beetle.

Chemical sprays and dusts are useful primarily against leaf-eating insects which feed on the outside of the tree; they are poisoned by eating the chemicals. Insects having soft unprotected bodies and working on the outside of the tree may be destroyed by contact insecticides.

In forest nurseries the value concentrated on small areas justifies the use of chemical sprays and dusts to control the insect pests attacking forest nursery stock. Poisonous gases also find application in fumigating forest nursery stock and seeds. Before nursery stock is shipped to the field for planting it should be inspected and treated to prevent the dissemination of any insect pest.

Control by Collecting or Trapping

In foreign countries intensive methods of collecting and destroying the insects in the egg, larva, pupa, or adult stages by means of hand picking, various trapping devices such as bands of viscous substances encircling the tree trunks, the use of trenches, lights, etc., have been employed. Similar methods are already found to a limited extent in the United States, principally in connection with nursery management. The value of the timber protected must be very high to justify such methods of control in the forest, and forest crop production must be on an intensive scale. As yet collection and trapping of insects are not generally practicable in this country, though this method has been used to some extent in a modified form in combating the gypsy moth by treating the exposed egg masses with creosote solutions. In forest nurseries the method may occasionally prove applicable.

Trapping insects may be useful for obtaining information on abundance.

Control by Forest Management

It is evident that the relatively low value of the forest resource and the relatively high cost of applying many of the methods for controlling insects by direct action compel the forester to seek cheap but effective ways of minimizing his losses from insects. Intelligent forest manage-

ment over a period of years will often furnish valuable assistance in insect control at little or no direct cost. As the forest entomologist learns more about forestry and the forester more about the insects, new means of avoiding insect losses in the forest by inexpensive changes in the details of forest management are sure to be developed. Eventually this type of control should be the primary factor in holding losses from forest insects to a minimum.

Since many species of insects, particularly bark beetles and some other borers, prefer unhealthy, weakened, slow-growing trees in which to breed, it follows that efforts should be directed toward maintaining the forest crop in a healthy condition. The fertility of the site should be improved if possible by skillful treatment of the soil. This is especially important on dry warm sites, for in such localities insects thrive. If possible, thinnings should be made early and repeated frequently. All unhealthy and sometimes the slow-growing trees should be cut. In mixed stands, where the species differ in susceptibility to the attacks of a dangerous insect present or likely to appear, thinnings and other cutting operations can be directed toward the removal of the species most liable to injury. This is a helpful measure in controlling the gypsy moth in the forest.

Health and growth rates are, moreover, a function of age. With advancing age forest trees are likely to decline in health and vigor. An intelligent management singles out these old trees, whether occurring singly or in whole stands, and harvests them at an early date. Forest crop production never utilizes the physical life span of our important commercial trees, but on the average only the first 50 to 150 years, during which time the timber is more vigorous than later on. This shortening of the rotation and consequent disappearance of overmature timber as the forest is cut over and put on a crop production basis will assist in improving the health of the forest. However, good health and vigor in a stand will not guarantee immunity from serious insect attacks, as for example by defoliators.

A more adequate road system throughout the forest areas (the upbuilding of which was one of the chief contributions of the Civilian Conservation Corps), together with increased use of trucks for hauling logs, is making it more practicable each year for the forest manager to cut small scattered areas of timber as they develop infestations of some dangerous insect. The control by removal and utilization of infested trees of merchantable size without special expense and often at a profit will become one of the principal methods of control in the forest under proper management.

In theory, pure stands should be avoided as tending to furnish so much food of one kind that the rapid multiplication to an epidemic stage of an insect partial to this food is encouraged. Where option exists, mixed stands should be encouraged, but as a matter of fact pure stands will frequently, under intelligent management, be maintained for the reason that only one species will flourish on the area, as witness the ponderosa pine type in the Southwest, or because the pure stand is likely to be the most profitable to grow in spite of the insect danger. Preservation of these natural pure forests in as nearly as possible their original ecological conditions will assist in preventing insect outbreaks. Pure stands if restricted to small areas will prove satisfactory in many places.

Where pure stands are grown only on a site suited to the species the danger of their destruction by insect enemies is much less than when grown on sites unsuited to the tree. Most of the criticism found in forestry literature against pure stands will prove on investigation to trace back to unfortunate results from attempting to grow the wrong species on a given site.

The exact composition of a forest stand, where natural reproduction after cutting is involved, is difficult to control when silviculture can be applied only in the crude and inexpensive manner forced by economic conditions in most parts of this country. The forester will usually have to take the species which come in on an area and as the stand grows older effect such simple changes toward improved composition as can be accomplished without undue expense.

Cutting of forest products at the right time of year may reduce to the minimum the damage caused by insects, both to the products themselves before they are utilized and to standing trees in the forest. Freshly cut timber is attacked by boring insects and if cut in the season when such insects are flying must be utilized practically as soon as cut, and even then the freshly cut lumber may be injured. With timber cut in the fall and winter there will be a longer period for safe utilization and the cut products are less attractive to the insects than freshly cut logs.

As knowledge increases, specific plans of procedure in the cultivation of specified forest crops will be developed and applied. A few such plans have already been worked out. For example, it is now a common practice in the Northeast in growing eastern white pine to arrange the details of establishing the new crop so as to avoid damage from the pales weevil. This insect swarms to the cutover area after the pine timber is cut and breeds in the stumps. It is abundant on the

area for two growing seasons after the cutting and consumes young pine plants more than 1 year of age. Hence planting is delayed until the third growing season after the cutting, at which time white pine transplants are set out and grow without injury from the pales weevil. If a cheap means of destroying the pales weevil could be developed, 2 years' time in establishing the new crop of pine would be saved.

Another illustration which may be cited is the special treatment of eastern white pine to minimize the damage caused by the white pine weevil. This insect burrows in and destroys the current year's growth (and sometimes more) of the terminal shoot. One or more side branches bend up to replace the terminal shoot, creating a decided crook. The weeviling may be repeated every year or two, and many trees are ruined for logs. At least three methods of controlling the insect have been recommended and used.

The pine may be grown under a nurse crop of light-foliaged hardwoods such as gray birch or poplar. The white pine weevil attacks the trees when their crowns are exposed to sunlight and, under the cover of the hardwood, which grows faster and overtops the pine, does very little if any injury to the pine. When the pine is 25 or more years old it forms a closed stand under the hardwoods. The hardwoods can now be removed, and the pine though it will not be entirely free from subsequent attacks of the weevil will not be seriously injured, since the crooks formed on the individual trees in the closed stand will be small and readily overgrown. This method though good in theory badly restricts the growth of the pine, thereby lengthening the rotation. Also, obtaining the right kind of a nurse crop is not always easy.

Furthermore, this type of treatment at least within central New England territory exposes the pine to severe attack by the gypsy moth because the gray birch and poplar in the overstory are favored food plants of this insect, while the white pine is not eaten until the later instars of the insect develop. Without the birch and poplar in the stand the white pine will not be attacked, but with the food supplied early in the season by these hardwoods the gypsy moth larvae will be able to defoliate and kill the white pine. Consequently, elimination of favored food species like gray birch and poplar is advised to protect white pine from gypsy moth. It is an illustration of diametrically opposed treatment advised for the same species (eastern white pine) to avoid injury from two insects. Similar situations arise continually in the application of control measures for the various forest enemies. Decision as to the action to take requires good judgment and a balanced view of the entire protection problem.

Another method of controlling the white pine weevil is to plant so thickly that at least 1500 trees per acre survive at the time the plantation closes. This is likely to require an original setting of at least 1700 trees per acre. The thick stand guarantees early closure and crowding, which in turn keeps the crooks made by the weevil from developing into serious defects. A good stand should result, and it is to be preferred to using a hardwood nurse crop. The disadvantages are that the cost of establishing the planting is about one-third greater than with the usual spacing of 6 by 6 feet and furthermore the stand is so dense that an early thinning made at some expense may be required. On good soils in some parts of the white pine territory, planting 1200 trees per acre should furnish a stand sufficiently dense to avoid severe injury (Maughan 1930).

A third method for control of the white pine weevil is the one spoken of earlier in this chapter; it consists in cutting out and burning the infested terminals. Placing the infested leaders in cages having a mesh too small to permit the escape of the weevils but large enough to allow any insect enemies of the weevil to escape is reported by Holdsworth (1943) as being preferable to burning the tips. This is likely to be less expensive than either the nurse tree or the dense planting methods, except in a region where there are many untreated weevil-infested stands.

An effective method of control is to spray the leaders of white pine with a lead arsenate mixture before weevil egg-deposition in early spring. The buds and bark of all leaders must be thoroughly covered with the poison mixture.

DDT applied with a mist blower from a truck may prove effective for controlling the white pine weevil in stands where wood roads are located not more than 400 feet apart. The blower covers a strip 200 feet wide on each side of the truck.

Control by Quarantine

Foreign insects are particularly menacing, both those which already have been introduced and others not yet in this country. Against these insects, an additional method of control in the form of quarantine should be employed. Foreign insects when introduced into the United States are likely to develop into virulent pests. The gypsy moth and the European spruce sawfly are two well-known examples of insects falling within this class. Even though too many destructive insects have already been introduced, they are in fact only a few among other

dangerous species too numerous to mention that might be introduced if it were not for the constant maintenance of a quarantine.

One of the best preventive measures which the forester can take is to keep in force and strengthen the quarantine against foreign plant material. In dealing with newly introduced insects not yet widely distributed, efforts to delay their spread by temporary local quarantines and direct control measures, admittedly too expensive for permanent, widespread use, may be justified on the grounds that time is thus afforded to carry on research and perfect the local control measures which ultimately must be applied in protecting the forest crop.

A foreign insect introduced into a new country and able to adapt itself to the new climate often reaches the epidemic stage. It is helped toward this point because its natural enemies are lacking. Whenever possible these enemies, both predators and parasites, should be introduced as soon as the foreign insect is discovered.

CONTROL FOR SPECIFIC INSECTS

One or more insects have been selected from each of the four major groups which attack forest trees and are here discussed in reference to the methods of control which can be applied.

Leaf-eating Insects

Spruce Budworm. This important defoliator of northern forest conifers, principally balsam fir, though spread across the continent has so far caused its most extensive damage in the eastern Canadian provinces and the northeastern United States. Its control must be sought largely through silvicultural management that will salvage timber ahead of the budworm and if possible reduce the percentage of balsam in the forest.

Both Westveld (1946) and McLintock (1947) believe that the damage from spruce budworm outbreaks can be reduced, though not eliminated, by proper forest management. Damage from current attacks can be reduced by finding incipient outbreaks and directing salvage operations into such stands. The spruce budworm feeds on pollen, particularly of the staminate flowers. For this reason tall trees with crowns growing out in the open, which bear large seed crops, should be harvested. Such trees are the center of the outbreaks.

To develop a more resistant forest, spruce should be favored as

against balsam. This is a difficult thing to accomplish; in fact it may be impossible on some areas. To make salvage operations feasible the cutting cycle in the spruce-balsam forests should be reduced to 20 years, and a permanent road system should be maintained. As yet, forest land owners have not been persuaded to do this.

Graham (1935) states that control of the spruce budworm on jack pine depends on regulation of staminate flower production. This can be reduced by maintaining dense stands. Trees producing large crops of pollen should be cut.

Hodson and Zehngraff (1946) found in jack pine stands that large-crowned orchard type of trees and also suppressed trees bore heavier crops of staminate flowers than did codominant and dominant trees. They believe that, if thinnings removing the lower class trees can be made often enough to keep remaining trees vigorous, injuries from the budworm would be reduced to the minimum.

An efficient detection system which locates incipient outbreaks should be maintained. Stands in which such outbreaks have been found should be promptly harvested. Balsam fir, the favored food plant of the insect, should be grown on short rotations of 35 to 50 years and cut to the lowest merchantable limit. Aerial spraying with DDT offers promise of cheap control of outbreaks.

Gypsy Moth. Introduced more than a half century ago, this insect has established itself in central and southeastern New England. Its spread northward is restricted by low temperatures. Ultimately the gypsy moth should be controlled through forest management which develops dense well-stocked stands containing if possible relatively small percentages of favored food species.

It has been found that the mixed hardwood forest of southern New England if well managed usually can support only a low gypsy moth population. Such a forest is dense, well-stocked, protected from fire and grazing, and consequently has a deep leaf litter. Under such conditions predators and parasites of the gypsy moth are abundant.

The gypsy moth larvae when not feeding are attracted by the cool moist condition of the forest floor and come down from the trees and fall prey to predators on the ground. In improperly managed forests, where this litter is lacking, the larvae remain in the trees and are comparatively safe. Chemicals such as DDT can now be applied by aircraft at a relatively low cost. In areas subject to infestation such treatment probably would need to be repeated every 5 to 10 years.

Natural enemies have been increased by the introduction of parasites and predators which are now well established in the territory.

However, adequate control cannot be expected from natural enemies alone.

A study of control measures for fighting the gypsy moth shows that several intensive methods of control such as applying creosote to exposed egg clusters, spraying with power sprayers, and banding of trees to trap caterpillars have been employed. The fact that this insect is a serious pest of orchards and shade and park trees explains the employment of methods which would not be appropriate from the forestry standpoint.

Insects Feeding upon Meristematic Tissues

Western Pine Beetle. This insect is the most important of the bark-boring beetles which attack the virgin forests of ponderosa pine in California, Oregon, Washington, and Idaho. Methods of control consist in removing beetle-infested trees, or treating them by some of the methods already described (pages 219 to 221) so as to destroy the beetles in the trees. If the trees can be salvaged, then, in addition to the infested trees, those most susceptible to beetle attack should be cut. Increased accessibility and changes in logging methods are making it possible to carry on salvage operations in many places instead of leaving the treated trees unutilized on the area.

A difficult part of applying this method in the past has been the selection of the trees most susceptible to beetle attack. If selection is not made accurately, either many trees left are killed by the beetles within a few years or an unnecessarily large number of trees are cut, thereby reducing the subsequent growth of the stand.

Keen (1936) developed a system of classification for the individual trees in the stand which enabled him to arrange them in susceptibility classes. He states, "in general trees more susceptible are weaker, less vigorous individuals and to a certain degree those more advanced in age."

The lower crown classes on the whole proved to be the most susceptible. Trees became more susceptible with advancing age, but the vigor of crown was really the critical factor. Quality of the site affects crown vigor. Hence, trees on the poorer sites were more susceptible to beetle attacks than those on the better sites.

According to Keen (1936) the beetles are "Nature's silvicultural agents which relieve the pressure of severe tree competition or of critical growth conditions and tend to preserve a natural balance between growing stock and available supplies of plant food and soil moisture."

He considers the work of the beetles to be a combined thinning from below and a selection cutting of the older age classes with a marked tendency to concentrate on groups. It is this kind of cutting which he advises as a control measure.

On the tracts studied, removal of the highly susceptible trees (chiefly intermediate and overtopped trees) involved cutting 17 per cent of the volume. Removing those of intermediate susceptibility (mainly codominate trees over 75 years of age) took out an additional 39 per cent of the volume. On the poorer sites removal of both these classes (56 per cent of the volume) is advised.

This is lighter than most cuttings previously made in the ponderosa pine type although the tendency today from the forest management standpoint is toward lighter cuttings. Further study by Keen and Salman (1942) developed an additional classification of individual trees in the susceptible class on the basis of current health symptoms indicating whether or not the tree was a high risk as far as early attack by beetles was concerned.

The ideal cutting from the protection standpoint would be to log over all hazardous forest areas each year, removing the actual or potential "bug" trees. This, however, is too intensive a type of forest management to be practical.

Instead the forest should be cut over on a short cutting cycle, removing 15 to 25 per cent of the total volume, the trees to be cut being selected on the basis of their insect risk rating. This plan is now in operation in some forests with successful results in reducing losses from bark-beetle damage.

Even this type of cutting may be so light as to prove economically impracticable on many relatively inaccessible tracts, but nevertheless it may be cheaper than direct treatment of infested trees and be much more effective than such treatment in reducing the losses from the western pine beetle.

The actual cutting adopted on a tract should be a compromise based upon what is best for the growth of the stand, in view of the economic possibilities and the insect risk.

Pales Weevil. The pales weevil though distributed through the eastern United States and southeastern Canada is best known as a dangerous enemy of eastern white pine reproduction, making the establishment of a new crop after cuttings a difficult matter (Peirson 1921). The beetles, attracted by cuttings, breed in the stumps and slash and in the beetle stage feed upon the bark of seedlings 2 years old and older. The smaller seedlings usually are killed outright. Seedlings

over 3 feet in height may suffer injury to the branches but are not likely to be killed. The weevils are most destructive on the cutting area the summer after the cutting and do considerable damage the second summer but are gone by the third season.

No method of direct control can be used, and dependence must be placed on either:

1. Obtaining a dense stocking of seedlings (10,000 or more per acre). Usually if seedlings are abundant not more than 80 per cent of them will be killed by the weevil and the remaining 20 per cent will be adequate to form the new crop. A two-cut shelterwood method could be used under this plan. The first cut should be made at the time of a seed year and the second could follow in 5 to 10 years when a sufficient amount of reproduction had become established.

2. Waiting until the beetles have left the area and then plant. This will be the third growing season after the cutting. Friend and Chamberlin (1942) found on one tract that planting could be successfully done in the second year after cutting with a loss of only 15 per cent of the planted trees.

White Grubs. These larvae of the May beetles are destructive feeders upon the small roots of trees in the eastern half of this country. Noticeable damage occurs chiefly on young trees in nurseries or in recently established plantations, although natural reproduction is sometimes destroyed. The insects cannot be controlled at reasonable cost in plantations, and areas having a very high population of white grubs should not be planted. In forest nurseries white grubs ordinarily can be controlled. The fact that the beetles deposit eggs in vegetation-covered but not bare fields furnishes the key to one method of control. Grassy fields should not be used immediately for nursery stock but should be plowed and kept in clean cultivation for 2 to 3 years, which is long enough to provide for the emergence of the insects already in the ground. The May beetles during their flight in the spring may deposit eggs in the dense seedbeds, but this can be prevented by screening the beds with ¼-inch mesh wire. This, however, is too expensive a method of securing protection. Since the grubs do relatively little damage the first year of their life and seedbeds are ordinarily kept only until the second year, little damage is experienced in unscreened seedbeds. After use as seedbeds the ground if infested should be allowed to lie fallow for 2 years, and, in general, crop rotation should be practiced. The nursery paths and unused areas should be kept free of vegetation, particularly in the spring when the adult beetles are flying. Where practicable, allowing chickens or hogs to have the run

of newly plowed ground that is infested will reduce the numbers of the grubs.

When nursery ground which has to be used continuously becomes infested with white grubs they may be killed by applying arsenic in powdered form to the soil. Small applications at the rate of 80 pounds per acre applied at intervals 2 to 3 years apart should be ample to eliminate the grubs. Where too large amounts of arsenic are used, browning of the needles, lessening of growth, and killing of many plants may result. Arsenic has not proved successful in all nurseries (Wakeley 1935, pp. 57–58), and it must be used with caution because in some cases the nursery stock has been injured. Recently introduced chemicals, such as DDT, may prove successful in treating nursery areas infested with white grubs and larvae of such species as the Japanese beetle, and the new chemicals are likely to replace arsenic for this purpose. Mitchell (1939) suggests that acetic acid applied to seedbeds will control white grubs and will not injure the plants.

Mound-Building Ants. The mound-building ants common in northeastern United States may kill trees, which are shading or threatening to shade their mounds, in a rather unusual manner. They inject formic acid into the cambium region and thus girdle and kill the tree (Peirson 1922). Around individual mounds the trees are often killed for distances of 20 to 30 feet. The damage is most common in plantations made on lands formerly cleared, although the same type of injury can be found in naturally reproduced stands.

The method of control consists in exterminating the ant colony. This can be done by introducing into the mound a heavier-than-air gas which will permeate the mound to its bottom. In applying the method several holes are punched in the mound and the liquid carbon bisulphide or ethylene dichloride is poured in. The holes are then covered with dirt and tamped down (MacAloney and Hosley 1934).

Experiments by Chapman (1948) have indicated that a 5 per cent concentration of Synklor dust, a commercial product that contains chlordane, can be used effectively to exterminate ant colonies. If the dust is applied in an 8-inch band to the periphery of an active ant mound at least one day before rainfall, activity can be expected to cease within 24 hours, and the colony should be exterminated within a few weeks at the latest. About one-half pound of dust, costing at present about 10 cents, is needed for a circular mound 1 yard in diameter. Since chlordane is easily applied, is no more toxic to animals and human beings than is DDT, and promises to be less expensive in

the future than at present, it should provide an excellent means for controlling the mound-building ant.

Locust Borer. This insect furnishes an example of bark-boring beetle that attacks not only the cambium region but also the wood of the stem. Eggs are deposited in bark crevices. The larva after hatching must bore through the bark in order to complete its life cycle in the outer sapwood. The more vigorous the tree, the less likelihood that the larvae will survive and do any damage to it. The dominant trees suffer the least injury, and the overtopped trees the most. Control must be secured by silvicultural management. The treatment depends primarily upon the condition of the stand; as advised by Hall (1933) it is as follows:

1. Slowly growing young stands. Black locust is being used so extensively for planting eroded lands where soil conditions are poor that undoubtedly great areas of black locust will fall into this group and be destroyed by the borer unless treated. In order to increase the vigor of these stands they should be cut back to the ground 4 or 5 years after planting before they become infested with the borer. The succeeding crop of sprouts should be so vigorous as to suffer relatively little injury from the borer. The sprout clumps should be thinned, leaving only the best sprout in each clump.
2. Severely injured stands should be treated in the same manner as slowly growing young stands.
3. Moderately injured stands should receive a thinning which removes the overtopped, intermediate, and weaker codominant trees with the object of reducing the population of borers and increasing the vigor of the remaining trees.
4. Mixed planting of black locust with other species should make a denser stand than pure locust, improve soil conditions, and thus assist in producing vigorous growth.

Sap-Sucking Insects

Numerous forest insects, such as scale insects and aphids, are included under this group. Though quite variable in character they are all alike in being difficult to control in the forest at reasonable expense. In nurseries the application of contact insecticides will prove effective against them. Treatment of this type will frequently be necessary and can be afforded.

In the forest the use of contact insecticides is too expensive. Furthermore, after trees pass early youth many of the sap-sucking in-

sects, while reducing growth, do not kill the trees except relatively few of the weaker individuals. Exceptions occur, for example the golden oak scale, an introduced insect which may kill a large proportion of the trees in stands of chestnut oak (Parr 1937).

Good silvicultural practice, which aims to keep the forest in a healthy vigorous condition, should result in minimizing losses from sap-sucking insects. When plantations are made, stock not infested with the insects should be used.

Wood-Destroying Insects

These insects ordinarily do not attack living trees. The species in this group which attack cut logs are of interest to the forester because often he must protect his product until it arrives at the point of manufacture.

In the warm season of the year, logs must be manufactured immediately after cutting; otherwise they may be riddled by boring insects. Unless logs can be sawed up at once it often will be advisable to carry on logging operations only in the fall and winter and arrange to saw the logs before insects are active in the spring. Logs can be kept safely in log ponds but frequently this is impracticable.

The pine sawyer has caused serious damage to eastern white pine logs and round-edged plank by boring through the sapwood. Hosley (1928) states that, for central New England, white pine round-edged plank sawed between September 1 and March 1 is not injured. The adult beetles lay eggs in logs and round-edged plank between May 15 and September 1. Eggs hatch into larvae which tunnel down to the heartwood. The insects will lay eggs only in logs and plank with a very definite moisture content.

DETECTING THE PRESENCE OF INSECTS

The development of effective control and preventive measures requires detailed knowledge of the local habits of the injurious insects and their interrelations with the complex life of the forest. This information can be best secured by a forest entomologist. To be a good forest entomologist a man must acquire not only training in entomology but also sufficient knowledge of silviculture so that he appreciates the forester's viewpoint and understands his problems. Otherwise the advice which he offers, even though entomologically sound, may not

be susceptible of application either because of its cost or because of its interference with the purposes of the management.

Close cooperation between the forest entomologist and the forester is essential if the best practicable methods of insect control are to be found and applied with the least interference with other objectives. The local forester should understand enough about insects so that he can detect their presence in his forest and recognize the dangerous species occurring in his locality. He should be able to distinguish between the normal infestation in the forest and any unusual activity manifested by an insect. Careful examination and tallies of infested trees on sample areas may be needed to build up and check the forest officer's judgment.

Insects reveal their presence by various signs, such as fine dust from their borings on the ground or on tree trunks, holes in the tree trunks, excrement, exudation of pitch, the withering or coloring of foliage, a bare appearance of the tree tops, bitten off and partly devoured foliage on the ground, and the presence in the stand of an unusually large number of insectivorous birds.

Eventually the forester should become as efficient in preventing and controlling insect depredations as he is in dealing with the forest fire problem.

H. B. Peirson (1947), State Entomologist of Maine, has been a pioneer in the movement to build up a state-wide organization, tied in with the fire protection system, for reporting outbreaks of forest insects. These reports are closely followed by field inspection of the areas, and recommendations for control are sent to the owners. Control is ordinarily by means of cutting the trees on infested areas. The adoption of similar systematic plans by all the forested states is much to be desired and should eventually keep losses from insects at a reasonably low figure.

The federal government should cooperate with the states in the movement to develop an organization to handle insect prevention and control. Government funds at least equal in amount to those now spent on fire protection could be allotted advantageously to protection against insects. The organization and the training of a special force of men for the forested portions of Canada have been advocated by Koroleff (1936). On each large timber tract he would have a man responsible for forest insect prevention and control. These men should be given simple training, and gradually an effective organization would be developed.

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CHAPTER 17

Protection against Domestic Animals: Grazing

INTRODUCTORY

The livestock industry is an important branch of agriculture. As operated in many parts of the country it involves the turning out of the animals into the field and forest for part of the year at least to forage for themselves. Consideration of the livestock industry as a business is not within the scope of this chapter, which instead will be devoted to a discussion concerning the influence of domestic animals upon the forest.

The common domestic animals exerting direct influence upon the forest are cattle, horses, mules, asses and burros, swine, sheep, and goats. These animals are distributed through all parts of the United States. On the basis of number of animals, the region from eastern Nebraska to eastern Ohio and from the southern part of the Lake states to St. Louis may be considered the center of the industry. Sheep furnish an exception to this statement, more than 50 per cent of the sheep being found in the West.

Grazing of forest areas is common throughout the country but permitted to much greater extent in some parts than in others. The livestock industry of the western United States, with the exception of those few sections favored with abundant precipitation and mild climate, is dependent to a large extent upon forested grazing lands or upon elevated areas of grass and brush land so interspersed among forested areas as to require management as part of the forest property. The best summer forage is in or adjacent to these forested areas. The same land is often utilized for the two purposes of timber production and grazing. This situation, even in the western forests, cannot be

considered good policy as a permanent measure in the majority of timber types.

In the eastern half of the country systematic continuous use of the forest for grazing purposes in conjunction with timber production is rarely if ever justified. More favorable climatic conditions, obviating the need of summer pasturage in the forest, partly explain this fact. Another reason is that the density of the forest cover largely eliminates abundant palatable forage. This situation is not confined entirely to the eastern half of this country. In regions such as the west coast of Washington and Oregon, with climatic conditions favorable to the development of dense forests, forage of commercial value is not found under the heavy forest canopy once the stand becomes closed.

Unfortunately, even within the regions having favorable climatic conditions, there are thousands of forest landowners, particularly those with woodlots held in connection with farms, who still pasture domestic stock in their woodlands for the purpose of securing shade, shelter, exercise, or food.

It is doubtful whether as much as one-quarter of the commercial forest area in the United States would carry forage of commercial value provided the forest was stocked with trees to its capacity. The present understocked condition of the forested areas, caused by past mismanagement, has resulted in a much greater development of forage plants than can be maintained when once the forests, after receiving correct treatment, become fully stocked. Most of the forested areas which are grazed today are in this understocked condition and are occupied by a relatively open forest. Eventually very few forest types if fully stocked will be capable of furnishing abundant forage.

In a fully stocked forest the trees make use of the available supply of moisture and nutrients and usually cover the ground with a layer of litter. The net result is that most of the lesser vegetation palatable to livestock is crowded out entirely or is sparsely distributed. Many of the plants capable of living under dense cover are of little value as forage. A few relatively light-demanding species of trees may be able to grow in fully stocked stands and at the same time provide considerable amounts of forage for livestock.

Species of this sort are found principally in the western half of the country. The aspen type, for example, occurring throughout the Rocky Mountain region on the moister soils, forms a rather open canopy which permits the growth of an abundant ground cover of herbaceous and shrubby plant species palatable to livestock. Even aspen stands can be damaged seriously by heavy browsing on foliage and twigs.

Approximately half (246,000,000 acres) of the commercial forest in the United States is grazed (Chapline and Campbell 1933). An additional 88,000,000 acres of noncommercial forest is grazed, 74 per cent of which is located in the West. The following table gives estimated percentages of the commercial forests which are grazed in the different parts of the United States.

PERCENTAGE OF TOTAL COMMERCIAL FOREST LAND BY REGIONS IN THE UNITED STATES GRAZED BY LIVESTOCK

(Compiled from figures given on pages 122 and 528 of *A National Plan for American Forestry*)

Region	Per Cent	Area of commercial forest grazed, acres
New England	12	3,150,000
Middle Atlantic	13	3,655,000
Lake	19	10,852,000
Central	37	23,635,000
South	67	126,870,000
Pacific Coast	55	36,411,000
North Rocky Mountain	57	18,330,000
South Rocky Mountain	76	23,359,000
Total	50	246,262,000

These figures indicate that larger portions of the forest are grazed in the South and the West than in the northern and eastern parts of the country. Some of the heaviest and most injurious grazing within the commercial forest is found in the corn belt states of the Middle West. The South, where more than half of the commercial grazed forest is located, is unique in that millions of acres of land are grazed by nonowners of the property without any payment for such use of the land. This grazing is accompanied by the frequent burning over of the land allegedly to improve the forage.

Even though there may be considerable forage growing within the forest, its quality is not equal to the same amount of forage grown on areas which are not forested. The feeding value of forage plants grown under the shade of a forest is much less than that of plants grown out in full sunlight, as shown by the following figures taken from Welton and Morris (1926):

	Dry Weight of Bluegrass, Pounds per Acre	Per Cent of Weeds	Net Yield of Bluegrass, Pounds per Acre
In open pasture	1126.7	40	676.0
In woodland pasture	347.9	75	97.4

Their investigations carried on in Ohio showed that, pound for pound of actual bluegrass, woodland pasture contained 22 per cent less total nutrients than were found in open pasture. Furthermore the actual yield of bluegrass (the principal forage plant on the areas studied) was much lower in the woodland pasture than in the open pasture. It is also probable that grass grown in the shade is less palatable than grass grown in the open because of a smaller content of sugars and starches. Similar results were secured in Wisconsin (Ahlgren et al. 1946) where woodland pasture produced 276 pounds of dry matter per acre in contrast to 1453 pounds per acre for open pasture (untreated) and 3210 pounds per acre for open pasture (renovated).

THE EFFECTS OF GRAZING

Grazing damage ranges from scarcely noticeable browsing upon the lower branches of forest trees through a variety of effects up to complete destruction of a forest. This extreme type of injury may be effected either (1) by the permanent prevention of reproduction, the area being left bare after the existing stand eventually dies a normal death, or (2) by actual killing of the existing forest.

Numerous and striking examples of the ability of domestic livestock to destroy the forest can be found in the Central States (Day and Den Uyl 1932).

Forests are not equally susceptible to injuries from grazing. Hardwood forests are more easily injured by browsing but after being injured recover better than conifers. Since the animals prefer to browse upon hardwoods, grazing usually favors conifers as contrasted to hardwoods in mixed stands. In the eastern half of this country, where conifers often compete unsuccessfully with many aggressive hardwoods, pure stands of a conifer frequently are developed, instead of a mixture weak in conifers, solely as a result of the selective browsing of domestic animals, which feed preferably on the hardwoods.

There is also a wide difference in susceptibility to grazing damage between species. Yellowpoplar suffers badly from cattle grazing while oak is only a little injured.

The effects of grazing upon the forest may be subdivided into:

Effect upon the soil.
Effect upon reproduction.
Effect upon trees past the reproduction stage.
Effect upon the control and prevention of forest fires.

Effect upon the Soil. The physical condition of the soil is injured by the trampling of the animals. They compact and harden the soil. Erosion is often started on slopes where the ground cover is closely browsed or destroyed (Forsling 1931). Trampling, particularly by animals with sharp hoofs, has a loosening and cutting effect upon the surface of the soil, which may be washed away in succeeding rains. Sheep and goats with their short tread and sharp feet are particularly injurious to the soil.

Grazing is one of the chief causes of erosion throughout the United States, particularly in the western half of the country, although examples of heavy grazing resulting in erosion can be found in almost any region.

Erosion, however, is not a necessary consequence of grazing, for grazing when properly managed can maintain the land in excellent condition. It is overgrazing rather than a proper amount of grazing which must be prevented if erosion and other injuries to soil are to be avoided. Overgrazing results in cropping the grasses and other forage plants so close to the ground that their effectiveness as a plant cover for preventing surface runoff is destroyed. Many of the forage plants may be killed by a continual overgrazing, thus decreasing the density of the soil-holding cover. One effect of compacting the soil and destroying the herbaceous ground cover and reproduction is that surface runoff is increased. In other words, the rainfall instead of filtrating into the soil through a porous forest floor runs rapidly off a bare compacted surface and is lost to that area; it also is likely to increase flood damage down stream. For example, measurements taken in Wisconsin (Anonymous 1938) showed that on slopes of 25 to 35 per cent large quantities of water were lost by the farmers who grazed their woodlots. The grazed forest lost in runoff 579 barrels of water per acre; the ungrazed forest lost only 10.3 barrels; and bluegrass pasture lost 213 barrels.

Erosion is of special concern on watersheds surrounding municipal and other types of storage reservoirs.

There is more danger of pollution on grazed watersheds as well as much more rapid silting of reservoirs.

Effect upon Reproduction. Reproduction because of its nearness to the ground is within easy reach of animals and consequently suffers more injury than larger trees. Seedlings and young growth are severely damaged by browsing. Not only are many eaten, but others may be broken, bent, or trampled by the animals. Roots may be exposed and barked. Sometimes bark is gnawed or peeled from seedlings. Goats

in particular inflict this type of injury; they are considered the most destructive to reproduction of all the domestic animals. As a result the trees are deformed and lose increment. Frequently small seedlings are destroyed. If not killed, injured seedlings may eventually grow in height until their crowns are above the reach of animals. In such cases the deformities received in early youth may be outgrown by the time the tree is ready for cutting. Pearson (1931) found this to be true for ponderosa pine seedlings which had been badly deformed by repeated browsing but finally grew out of the reach of browsing animals. If a ponderosa pine seedling once attains 4 to 6 inches in height only excessively heavy grazing is likely to kill it. According to Cooperrider (1938) recovery of a pine tree from browsing injury depends primarily on its ability to develop extra buds (usually dormant buds) to replace the lost shoots. Dormant buds develop abundantly on grazed-off stubs of ponderosa pine seedlings.

Hogs eat the seeds of certain species such as the oaks, and uproot and devour the roots of the longleaf pine. Indeed, hogs are a primary factor in preventing longleaf pine reproduction by uprooting practically all seedlings over extensive forest areas.

In addition to injuring or destroying existing reproduction, animals through their effect on the soil may create seedbed conditions unfavorable for the start of reproduction. Sometimes their influence upon the seedbed may be beneficial, especially that of hogs which in their search for food mix the litter and soil and may expose the mineral soil. Where, in a mixed stand, species with palatable seeds are less desirable in management than others with inedible seeds and a preference for a mineral seedbed, hogs may be of distinct benefit. For example, shortleaf pine in mixtures of oak is favored by the grazing of hogs.

In stands containing both conifers and broadleaved trees, grazing animals usually browse the foliage and branches of the broadleaved trees, thereby favoring the development of the conifers. Where the seedbed created by the grazing is suitable for the reproduction of the conifers, as is often true, a pure stand of conifers may be established. On the whole, the natural reproduction coming in on grazed areas in mixed hardwood stands is likely to have a higher percentage of inferior species than the original stand. Sometimes woody shrubs replace tree species as a result of grazing. Where several tree species are reproducing on the same area, browsing on the palatable species may affect the composition of the new stand either favorably or unfavorably, though usually the latter.

The loss of all or a portion of the reproduction may result in inade-

quate density of stocking, which in turn means a lower increment or reduced quality of product and in extreme cases the ultimate destruction of the forest. Loveridge (1924) cites examples where Engelmann spruce reproduction has been prevented by too heavy grazing of sheep.

Grazing may be favorable at one stage of regeneration and unfavorable at another. For instance, it may create excellent conditions for the germination of seed and for the early growth of seedlings but its effect on subsequent development may be bad. Hence to determine the exact effect of grazing upon as delicate a process as the establishment of natural reproduction requires careful investigation.

Sometimes grazing is of assistance in establishing reproduction either by preparing a seedbed favorable for the early survival of seedlings or by reducing to a minimum the competition of grasses, herbaceous plants, and shrubs with the reproduction. Pearson (1934) has shown such competition to be a critical factor with ponderosa pine.

The cumulative effect of the destruction of reproduction over a long series of years is finally the destruction of the entire forest. As the older trees die or are cut they are not replaced by young growth. The stages through which a hardwood forest passes in this gradual process of destruction are well described by Day and Den Uyl (1932).

Effect upon Trees Past the Reproduction Stage. When trees have once elevated their crowns above the reach of animals they are free from serious direct injury by domestic animals. Injury may be done by trampling and barking exposed roots or by rubbing (principally by cattle) and by the compacting of the soil so as to hinder aeration. The chief loss is a reduction of the stocking and increment of the stand resulting from the injurious effects of grazing upon soil. Shallow-rooted species are likely to suffer more injury through trampling than deep-rooted trees.

The compacting of the soil and the grass growth, which often results when stock have destroyed the forest litter, affects injuriously the supply of moisture in the ground available for tree growth (Tillotson 1927). Trees of all sizes may be seriously affected and usually indicate their ill health by becoming stagheaded. Such trees may eventually die. The grazing if prolonged for many years may so change soil and moisture conditions as finally to destroy the entire stand.

In sugar maple stands where maple sirup is a primary product grazing may result in decreased yields. Dambach (1944) estimated the loss in value of maple sirup production on grazed areas at $10.67 per acre per year. The loss is attributed to absence of an adequate forest litter in the grazed stand which affected the water-holding ca-

pacity of the soil and the depth to which the soil froze during the season of sap flow.

Overgrazing by injuriously affecting the health of the forest makes it easier for insects and fungi to attack the trees. Grazing, particularly in hardwood stands, destroys the cover for birds and consequently assists in driving them from the forest, to the benefit of the injurious insects upon which many of the birds feed (Day 1930).

Continued heavy grazing that prevents reproduction compacts the soil, exposes the tree roots, destroys the forest floor, and brings in a grass sod as substitute for the normal forest floor; these changes in site conditions will ultimately destroy the forest itself (Den Uyl 1945). This is the final effect, already apparent in many places.

Effect upon Fire Control. Grazing has a distinctly beneficial influence in reducing the forest fire danger. Grasses and forage plants when present in the forest constitute the most readily inflammable portion of the fuel for fires. When this is removed by grazing, the fire danger is reduced, the start of a fire being rendered less easy and sometimes its rapid spread made impossible. Livestock often assist in breaking up slash and dead material and thus hasten decay. The beneficial influence of grazing upon fire protection may offset all injury caused to the soil and the forest.

This effect of grazing has been recognized in a variety of widely distributed forest types. Hatton (1920), after studying the subject in reference to conditions on the national forests, concluded that normal grazing decreased the number and the spread of forest fires, and he recommended more intelligent use of the livestock industry to assist in the prevention and control of fires. Ingram (1928) has also recommended properly regulated grazing as a fire prevention measure.

The custom of setting fires each year in the winter for the purpose of burning off the dead grass, thereby enabling livestock to reach the tender new shoots, still prevails in parts of the South. It is based on the premise that such action improves the grazing. As a matter of fact Greene (1933) has proved for the longleaf pine type that cattle gain more weight on burned than on unburned pastures, the increase coming in the early part of the season. Both the quantity and quality of forage were increased on the burned area. The grass starts growing earlier on burned areas because of higher soil temperatures, while on unburned areas it is smothered by the litter. If the returns of a single year are looked at and the gain in weight of livestock is the chief consideration, burning appears advantageous. There are other sides to the situation that usually make it undesirable to burn annually, even

in such a fire-resistant type as longleaf pine where fire at less frequent intervals may be advantageous for reasons other than for forage production.

The stockman of course knows that if he can destroy the forest by fire or other means more light will reach the ground, less organic litter and tree reproduction will cover the soil, and consequently there will be more opportunity for grasses and other forage plants to develop. Hence in some parts of the country the livestock industry has been a distinct menace to the proper control of forest fires.

BENEFITS VERSUS INJURIES FROM GRAZING

The extent of the injury from grazing to the production of tree crops is exceedingly difficult to estimate, since the major portion of the loss accrues to young reproduction and to soil conditions resulting in a loss of increment and a reduction in density of stocking. In the sections of the country where the forest occurs principally as scattered farm woodlots, grazing is the primary source of injury and leads to complete destruction of the forest.

Grazing at first sight appears beneficial to the community as a whole, producing relatively large annual receipts expressed either as rents for grazing privileges or as values of domestic animals supported. In regions where the management of livestock is important, damage to the forest often is considered incidental to and a necessary consequence of the grazing industry. Places may be found all over this country where portions of the forest should be abandoned, as such, and kept as open groves for their shelter to livestock, or else the land should be cleared entirely of trees and put into open pasture.

On most forested areas the forest should be considered first, and only such an amount of grazing should be allowed as will not injure the forests or alter their influence. The national forests, for example, fall within this class of land and require such management of the grazing as shall not interfere with the primary purposes of timber production and watershed protection.

Too little consideration has been given the question of the relative benefits likely to follow from the use of given areas of land for the production of trees or for grazing purposes and the extent to which the two can be combined profitably upon the same areas. Until this information is secured, it may be difficult to determine whether in specified forest areas certain of the harmful effects of grazing should be tolerated or prevented. In general, areas classed as forest lands will return a

higher profit from tree crops than from livestock and should be devoted exclusively to the former purpose. Only in those forest types which normally, in fully stocked stands, provide abundant palatable forage should grazing be considered in conjunction with timber production as a permanent combination.

Southern pine lands in their present average understocked condition have forage available for cattle. Grazing, carefully controlled as to number of animals and season of use, can be of benefit by furnishing a cash income while the forest is being built up to full stocking. Grazing at this stage is beneficial not only from the financial standpoint but also in assisting pine reproduction through reduction of grass competition and in reducing the fire danger (Campbell and Rhodes 1944). Intelligent livestock management, which is spreading throughout the South, tends toward less reliance upon woodland grazing, except in a part of the year, and more upon other pasturage and feeding. Thus, as the pine forests become fully stocked and crowd out most of the forage, the industry will be in position to thrive without much woodland grazing.

As studies are made, the evidence is becoming more concrete that timber production pays higher returns than grazing on forested areas. In Ohio woodlots the returns from timber growing are estimated at several times the returns from pasturing livestock in the same areas (Tillotson 1927).

Within the timber zone in the California pine region production of not less than 50 cents per acre per year in growth of timber is estimated (Show and Kotok 1924), whereas the annual return from grazing does not exceed 15 cents per acre on the best areas. Pearson (1935) estimates the annual increment of ponderosa pine stands at 15 to 25 cents an acre and the annual forage crop on the same areas as worth 1½ cents per acre.

These are only a few examples showing what appears to be the general situation. So far as is known every investigation which has been made comes out with this same conclusion. There are, of course, scattered pieces of forest land which may have agricultural value, and they might well be cleared and be put to producing such crops. Forest land which is not of this character, however, will pay better returns to the community in the long run when used for the production of trees rather than of livestock. This fact justifies efforts to prevent further serious damage to the forest from domestic animals.

Since the livestock industry is a going business with income returned each year, whereas the growing of tree crops is in its infancy and often

cannot yet pay annual returns, it is difficult to bring landowners to a correct point of view and get them to give the production of forest crops the priority that it merits. The raising of livestock by means of food picked up by the animals roaming in wooded pastures is a crude type of land use which deserves to be discontinued just as fast as correct land-use management is applied.

Stockmen sometimes take the viewpoint that forest lands have a higher social value for livestock production than for timber growing, in other words, that the community would benefit by the continuation of forest grazing rather than the development for producing forest products. On analysis this position will usually be found incorrect; the greatest community benefits in the long run will come from full production of forest products. Pearson (1935) estimated that 10,000 acres of ponderosa pine land in the Southwest if grazed provided 300 to 900 man-days of labor, depending on whether cattle or sheep were grazed, whereas the same land under good forest management could furnish 1800 to 3000 man-days of labor depending on whether management was extensive or intensive.

METHODS OF CONTROL

Methods of controlling injury from grazing may be summarized under the following two headings:

Exclusion of livestock from the area to be protected.
Regulation of allowed grazing.

Exclusion of Livestock. The most satisfactory method of controlling injury by livestock, from the standpoint of forest production, is complete exclusion of animals. This method, though already involuntarily in operation in many forest areas where fully stocked stands have suppressed the forage plants, is too drastic to fit present economic conditions in many parts of the country. Established livestock interests organized to utilize the forage available today in the open, mismanaged forests understocked with trees and overstocked with shrubby and herbaceous forage plants cannot be immediately divested of their opportunities for grazing without serious economic consequences. The exclusion of livestock must come gradually as the forest is developed into a productive unit, and thus opportunity is afforded for higher community prosperity than was possible during the forest-pasturage era.

With complete fire protection the forest is likely to become fully stocked. This will automatically decrease or exterminate the palatable

forage in most forest types and ultimately should tend to bring about the permanent exclusion of grazing animals on many areas now grazed.

Domestic animals may be excluded from an area throughout the entire rotation or only for the regeneration period. Exclusion for the entire rotation might be necessary in protection forests, where damage from erosion or floods might occur or the life of the forest be threatened. Elsewhere such an extreme measure is not always essential for the less injurious kinds of animals. In forests where grazing is exceedingly injurious, it may be necessary to exclude stock permanently, even though the forests are managed primarily for timber production rather than for protection purposes. If the grazing would result in destroying or compacting the forest floor, livestock should be permanently excluded.

Most of the direct damage by grazing to the forest is done during the reproduction period. The young plants are just at the stage when they can easily be killed by livestock and need protection until they are high enough to be beyond the reach of browsing animals. Hence, if animals are excluded during this period and then admitted for the rest of the rotation the direct damage to the forest in certain forest types may be reduced to an insignificant amount.

Selection stands are continually undergoing regeneration and consequently may need permanent exclusion of grazing. Usually when reproduction has fully stocked an area there will be available during the rest of the rotation only small quantities of forage, in most cases too small to be economically utilized by domestic livestock. Hence, where exclusion of grazing during the regeneration period is needed, such exclusion may often be permanent.

Since the effect of grazing upon reproduction is problematical, both injurious and beneficial effects being known, exclusion during the regeneration period should not be attempted in all forest types or regions. Such action may fail to take advantage of a favorable effect which grazing may have on the establishment of reproduction. In some although not in most instances, properly regulated grazing in the regeneration period may be highly beneficial.

An illustration of the application of this principle is found in the ponderosa pine forests of Arizona and New Mexico, where continuous heavy grazing is destructive to pine reproduction and may prevent the establishment of well-stocked young stands. Pearson (1934) has found, however, that grazing preferably by cattle if skillfully controlled can be usefully employed in the regeneration period. He suggests relatively heavy grazing at the time of a seed year and continuing

until the seedlings are 5 to 6 years of age, in order to minimize competition from grass, after which lighter grazing to avoid browsing injury is indicated.

In the longleaf pine type it is necessary to exclude hogs from areas being reproduced, because the hogs destroy the seedlings. Since livestock owners in many parts of the South are not required by law to fence in their livestock, it becomes necessary for the forest owner to fence out the other people's hogs. Sometimes it may be practicable to fence individual areas being reproduced, but oftentimes it may prove more economical to put a hog-proof fence around the entire tract under management. The construction, maintenance, and depreciation of such hog-tight fences are estimated to cost 6 cents per acre of area protected per year, if large tracts are fenced in (Forbes 1930).

The U. S. Forest Service has the authority to exclude grazing from areas within the national forests. Several million acres of lands formerly grazed in the national forests have been withdrawn from such use. It is to be hoped that further exclusions will be made as the forests become better stocked with reproduction and the productive power of these forests increases.

Regulation of Allowed Grazing. The principle which justifies the allowing of regulated grazing in the forest is that, if all forms of overgrazing are avoided and only that grazing is allowed that the available forage will satisfy, the damage to the average forest and soil will be insignificant. Under this system domestic animals are allowed to graze in the forest, but the kind of livestock, the numbers, season for grazing, and the distribution over the range of the animals are carefully regulated. This method is in successful operation over a large part of the national forests. It is much better suited to the character of the existing forest and to the present economic situation, particularly in the western United States, than the complete exclusion method. Each kind of animal has its own preferences as to forage and forest conditions and if possible should be located only on areas where its requirements can be met without injury to the forest. The most efficient use of the range will be obtained only when the right kind of animals are grazed. Cattle prefer park-like timber stands or woodland areas and the meadows found in openings throughout the forest. Sheep graze steep slopes, brushy areas, and dense timber in a more thorough fashion than cattle.

Experience has demonstrated that the injurious effects of grazing increase rapidly with the number of head of stock grazed on a given area. Until forage becomes scarce, the animals do not browse the less

palatable food furnished by trees. By properly regulating the number of animals, sufficient forage is provided for all animals without their having to browse upon the trees.

Beside restricting the number of animals allowed on an area, it will also be necessary to regulate the season during which these animals can graze. This is essential in order that forage conditions may be improved. The damage to the forest can be reduced not only by controlling the number of animals but also by increasing the amount and quality of the forage plants. The plants must be allowed to develop vigorously and to reproduce. If grazing is permitted too early, the forage plants may be cropped close before gaining adequate size and strength; also, if the ground is too wet, trampling and compacting of the soil may result. Grazing too late in the season is likely to injure the forage plants and the soil through too close utilization of the forage. The opening and closing dates of a grazing season are related to climate and weather and may vary from year to year (Costello and Price 1939).

Opportunity must be allowed at properly spaced intervals for the forage plants to produce seed and thus assist in maintaining fully stocked forage crops. Under constant close cropping throughout the growing season, seed reproduction of the forage plants may be prevented. To avoid this, deferred and rotation grazing should be practiced. Deferred grazing consists in delaying the grazing use of an area until the plants have matured their seed. Then, grazing the area at the time of seed fall may assist in establishing new forage plants by working the seeds into the soil through trampling. Rotation grazing consists in shifting deferred grazing to different areas each year. In this way the forage crop on any given area can gradually be increased.

Efficient regulation of grazing should maintain a satisfactory distribution of the animals over the range. If this is not accomplished the animals are likely to concentrate on certain portions of the range and there cause severe damage because of a shortage of food, while on other parts of the area available forage is untouched. Thus local overgrazing is likely to occur, even on portions of larger areas that as a whole are not carrying an excessive number of animals.

A uniform distribution of the animals over the range must be accomplished largely either through the development of properly located range improvements or by the methods used in herding the animals which, like sheep, are grazed in bands.

The range improvements which assist most in obtaining an even intensity of grazing use are watering places and salting grounds.

Fences to keep the stock on the allotted range may also be needed where natural boundaries are lacking.

On the national forests the Secretary of Agriculture has the authority to permit, regulate, or prohibit grazing. More than 80,000,000 acres of national-forest land are reported by the forester as suitable for livestock grazing. Over 5,000,000 cattle, horses, sheep, and goats are permitted to graze in the national forests under regulations which are intended to prevent injury by these animals to the soil and vegetation.

Outside of the national forests very little has been done to regulate grazing in forested areas. There is a large field for its application on tracts of all sizes from the smallest woodlot upward, particularly in the South where at present there is much free and unregulated grazing of forest areas by nonowners of the land.

The general trend of the livestock industry is toward more intensive methods of handling stock. As this affects the forest it means more improvements on the range for regulating the movement of stock, a restriction of the general running of livestock over wild wooded areas, and the increase of feeding in buildings and on well-kept pastures.

These methods should, on the whole, operate toward reducing the damage to the forest, because well-cared-for livestock are not so eager for the relatively low-quality forage provided by the forest. Moreover, the increasing realization by the livestock owner that his own interests are best served by a conservative management of the forage plants in wooded areas will tend to lessen overgrazing and, consequently, damage to the forest.

The problem of grazing control is not the same over the entire country. At least three entirely different situations can be recognized which the following quotation from Chapline and Campbell (1933, p. 527) well summarizes:

> The forest land grazing problem logically divides into three important phases: The western-range phase, that which predominates in the South, and the pasture type in the farm woodlands. In the West the problem centers around the utilization of large areas principally of public land by many private owners of range property and livestock. In the South it largely concerns the use of extensive private forest areas often not owned by the stockman yet of decided value to the rural population. In the farming regions of the Central States, and in parts of the New England, Middle Atlantic, and Lake States, it involves small woodland areas on farms into which the farmer turns his livestock.

It may be anticipated that in the West, where the national forest lands furnish the requisite summer forage, the use of forested lands as grazing grounds will continue indefinitely with grazing allowed under regulation. Gradually, as the western forests recover from past abuses and improve in density, grazing in the forest will decrease, but always open areas with forage will be interspersed in the forested areas. By continued regulation of grazing, damage can be kept at the minimum which will not interfere with timber production. The policy should be to encourage grazing while forest productivity builds up. Ultimately, returns from forest industry based on fully stocked forests should gradually reduce grazing in certain forest types.

Throughout the South a certain amount of livestock grazing can always be permitted in the southern pine types without serious injury to the timber. But, as organized timber growing and naval stores production develop, the fully stocked stands will furnish relatively little forage. Enough area of good soil exists so that in the long run livestock production will be concentrated on cleared areas. The exclusion of hogs and the regulated grazing of other animals in the pine types should be the aim. Grazing in the hardwood types, if allowed at all, should not be permitted on areas being reproduced.

Livestock should be excluded from the farm woodlots of the central and northern states throughout the rotation. Here grazing and timber growing should be on separate areas. All the land needed for permanent pasture should be cleared of the forest. The remaining forest should not be grazed. Exceptions should come only where temporarily, to secure the beneficial effect of grazing on the establishment of conifer reproduction, animals may be admitted in certain forest types.

In all forest regions control of grazing should be recognized as a problem for the forester to handle so that it gives as much revenue as is consistent with the primary purpose of forest crop production. Grazing is essentially a land use subordinate to timber production, watershed protection, and recreation. Where it injures the forest for these other uses it must be regulated or entirely excluded.

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CHAPTER 18

Protection against Wildlife: Animals Other than Insects and Domestic Animals

GENERAL CONSIDERATIONS

The term "wildlife" as used for the purpose of this chapter may be defined as including all animals other than insects and domestic animals, both of which have already been considered in previous chapters. It is evident that a great variety of animals of diverse habits and characteristics are grouped in the present discussion. They all have this in common, that they are studied here from the forest protection angle rather than from the standpoint of the management of wildlife as a natural resource in itself. It is already well recognized by foresters that wildlife is one of the natural resources connected with forest land, and a resource which oftentimes can be turned to profit. Indeed, the production and utilization of animal products may furnish substantial revenue from forests.

However, the viewpoint here is that of forest protection. Though recognizing the advisability of developing wildlife as a resource, this discussion is restricted to the influence wildlife may have upon the production of wood crops. In this connection the forester will always have an interest in wildlife management for the purpose of keeping wildlife down to such a degree of stocking as is consistent with an acceptable, i.e., not too great, amount of damage to the forest.

Although numerous animals are included under the term wildlife, yet the number of animals causing important injuries to the forest is relatively small. From the standpoint of forest protection, the various animals may exert either beneficial or injurious influence. In-

deed, the same animal sometimes both injures and assists the growing forest crop.

The principal animals classed as wildlife causing damage to tree crops include deer, beaver, porcupines, rabbits, mice, squirrels, and birds. Although the injuries inflicted upon the forest resulting from the work of these animals are less important in the aggregate than those caused by fire, insects, plants, or domestic animals, still relatively large losses on limited areas may ensue from the attacks of any one of the types of animals just mentioned.

In general, the damage caused by wildlife consists in the browsing of foliage, buds, and young shoots, in the gnawing of bark, often to such an extent that trees are girdled, or in mechanical injuries to the trees. Many trees are actually cut down by beaver. Sometimes injury from wildlife may be confused with that caused by domestic animals, but careful observation should serve to identify the injury actually caused by wildlife. In this connection, Pearce (1947) has compiled the characteristic signs whereby injury by wildlife to trees and shrubs in the northeastern forests can be definitely identified. The kind of damage varies greatly with the kind of animal responsible.

Before taking up in detail the damage caused by the various types of wildlife, it is desirable to discuss the principles governing control of wildlife damage as a whole. It is recognized that the wildlife in the forest must play an important part in the biology of the forest community. The wild animals live in a delicately adjusted relationship with one another and with their forest environment. Changes in animal relationships are likely to be reflected in a rise or fall in the population of given animals.

Changes in the wildlife equilibrium may cause changes in the amount of damage done to the forest. Conversely, changes in the forest brought about by cuttings, fire, or other causes are likely to result in changes in wildlife populations.

In the original forest there undoubtedly existed more or less a balance among the different forms of wildlife. This balance was by no means static, since virgin forest conditions are themselves subject both to continuous slow changes and to occasional radical and quick transformations. But it is unlikely that wildlife caused such serious damage to the original forest as that which has followed many of the changes wrought by man. The situation changed when man came on the scene and by his more radical and frequent interference with natural processes upset the biological equilibrium existing among the animals (Taylor 1934).

Although the forester has studied the ecology of the plants in the forest community and is familiar with the radical changes in the natural processes of plant succession which are caused by silvicultural operations, he has not realized fully that changes in respect to the development of wildlife, similar to those occurring among plants, should be anticipated in the managed forest.

The greatest damage to the forest from wildlife occurs in those places and periods of time when interference with the currently existing biological processes has caused some type of animal to multiply prolifically or to be restricted in its normal food supply. When either of these two things happens, the forest is likely to suffer unusual amounts of injury—so great that frequently steps should be taken to eliminate or minimize similar injury in the future. When such a situation arises the forester sometimes is tempted to exterminate an especially troublesome animal pest. This is usually difficult and unwise. Before undertaking such drastic action he should remember that each animal has its own place in the biological complex and its own function to perform. Any attempt to improve conditions by exterminating any of the wildlife requires full knowledge of the existing relationships.

Indeed, the principle may be accepted that for each forest area there will be a legitimate place for a given number of each species of animal suited to the region and period of development. This does not mean that every animal which existed in the original forest should be maintained, but, if only those animals suited to the region and to the period of development in which the forester is working are included, then it is best that all should be retained. The forester's aim should be to maintain, by inexpensive methods of management, the animal population at a desirable quantity, neither too great nor too small, for each species rather than to exterminate a species.

Much more investigation is needed before the proper place and function, in each forest community, of the different animals can be accurately stated. With the advance of civilization the details of land use and forest crop management are ever changing; hence it is reasonable to expect that the animal community typical of the virgin forest may be modified advantageously.

The most effective and least expensive method of eliminating, or at least keeping down to the minimum, injuries to the forest from wildlife will consist in maintaining such conditions as will prevent the building up of any animal species to abnormal numbers. This should eliminate food shortages and prevent serious damage to the forest. More accurate knowledge than we as yet have about the habits of the

numerous species of wildlife is needed before such action can be accomplished.

Direct action is also needed to reduce numbers of a given species of animal to a proper point, oftentimes by such methods as shooting and trapping the excess number of animals or even by the temporary use of such severe measures as poisoning to control some animals causing abnormal damage. Unfortunately, authority to do this is not always vested in the forest management, but in the long run it must be if injuries from wildlife are to be avoided.

For successful forest management the forester should know what wildlife population can be supported without appreciable damage to the forest and then must have the authority to reduce the excess population to acceptable numbers by forceful measures if necessary.

The opportunity exists for profitable combination of forest and wildlife management. Indeed, there needs to be such a combination simply from the standpoint of forest protection because wildlife is already present in most forests and requires management to avoid serious injury to the forest. Further than that, it may be possible to carry out the purposes of the landowners and to increase appreciably the revenues derived from a given forest area by a correct combination of forest and wildlife management.

As already explained, this book deals primarily with wood crops and not animal crops, recreational use, or other phases of the management of forest lands, which, combined, spell complete development for highest usefulness: For this reason a full discussion of methods of wildlife management of forest lands is out of place here, but it is most important to stress the fact that the best protection against serious injury to the forest from wildlife will be secured only when wildlife is managed scientifically to a greater extent than it is at present. The forester consequently should be interested, from the protective standpoint, in seeing that proper management of the wildlife resource is provided in his forest. He should be prepared to make certain concessions in order to get the benefit of the increased revenues from wildlife and better cooperation from those interested in the wildlife resource.

It is also recognized that, on properties which are handled primarily for development of the wildlife resource, considerably more damage to the forest may be done and will be accepted as unavoidable than on areas where timber production is paramount. Even on properties managed primarily for timber, it is questionable whether what could be termed excessive injury to the forest will be suffered, provided overstocking of wildlife is avoided. As knowledge increases, production of

timber and of wildlife in many instances can be conducted simultaneously upon the same areas, although to do so will require concessions from both sides. The management must show a high order of skill in execution and possess full knowledge of all essential facts to make such combined production a success.

Miller (1934) indicates that silvicultural practice usually has a favorable effect upon wildlife, although certain modifications of silvicultural practices may be required in order to make the most favorable conditions for game.

Where wildlife management proceeds along natural lines there is a better opportunity for a combination of forestry and wildlife than where methods of artificial propagation are used.

Gabrielson (1936) suggests certain modifications in methods which may be made both by the forester and by the wildlife manager to ensure a better combination of the two. As modifications by the forester he suggests that cutting operations be distributed each year in as small areas and as uniformly as possible. This is right in line with modern tendencies in silviculture and for reasons independent of wildlife should be developed in the forest as soon as possible.

He further urges that the planting of all the natural openings in the forest be avoided. The tendency in the past has been toward stocking every inch of open land with tree growth. From the aesthetic standpoint this is now recognized as undesirable and is certainly one of the concessions which might well be made to encourage wildlife and lend variety to the forest scenery. He also suggests that timber stand improvement work, particularly as it was at one time applied by the Civilian Conservation Corps, should be modified to avoid injury to wildlife. The suggestion is excellent. In the past too many of the trees and vines furnishing food for wildlife have been destroyed and oftentimes areas cleaned up too thoroughly for the best development of wildlife.

As a modification of the wildlife program, the game expert is advised to give the forester more consideration in planning the game-management program and fitting it in with other land uses. The forester because of his broader and more practical training is likely to be a better man to direct the administration of a forest property than a game expert. Gabrielson also suggests that wildlife planting programs be scrutinized to determine whether they are really needed and economically feasible, and finally that the effects of game refuges upon building up a proper stocking of wildlife and upon the character of the damage caused to the forest should be studied. When they have been

so studied, it is likely that regulations governing these game reserves will be found to need important modifications.

Cahalane (1939) talking of the Central States region where the fauna consists of small forms, advises single-tree selection cutting on small tracts. Piling and leaving unburned some of the slash provides shelter for wildlife. Clearcutting in small blocks or in narrow strips he considers the next best practice to single-tree selection cutting. The leaving of den trees and a variety of trees which the forester considers weed trees but which produce food for wildlife is advised. Thinnings are generally helpful to wildlife unless too rigid discrimination is made against food-producing species.

More intimate and more beneficial interrelations exist between wild animals and the forest than between domestic animals and the forest. In fact, wildlife fits in as an essential part of the forest and when properly regulated can be included permanently in the forest community without serious damage to the forest, whereas domestic animals must often be excluded.

DEER

All species of deer and elk are potential enemies of the forest in the sense that they will cause severe damage where overstocking occurs. The principal kinds of deer found in this country are the white-tailed deer, common in the eastern half of the country, and the Rocky Mountain mule deer which is the common species in the West.

The injuries caused in the forest by deer resemble those by domestic animals. This statement does not necessarily mean that they eat the same foods, but it does imply that the principal injury done is in the nature of browsing upon trees themselves and upon ground cover and underbrush.

Deer eat the same type of forage as sheep and goats and are nearer to these domestic animals than to cattle in their food preferences. On the whole they prefer browse and weeds to grasses. Robinson (1931) found that the deer diet was composed of approximately 60 per cent browse, 25 per cent weeds, and 15 per cent grasses and grasslike plants. Dixon (1928) observed that 60 per cent of the food that deer would eat was also taken by sheep whereas only 50 per cent of the deer food was taken by cattle. Both Robinson and Dixon were working in California, and their observations were concerned principally with lesser vegetation. Often a share of the grass forage will be left untouched where deer alone are grazing, while cattle would of course feed upon this forage. On the other hand the deer would eat freely of all kinds of

woody and shrubby browse which under ordinary circumstances would not be preferred by cattle.

A study of food habits of Minnesota deer (Anonymous 1938) showed that 45 species of plants were eaten during the fall but only 25 in the winter. Conifers formed three-quarters of the diet in winter but only a half in fall. Northern white-cedar was the most valuable as a deer-browse species.

Deer appear able to browse upon practically all species of trees found in the forest. Both hardwoods and coniferous trees are eaten. Undoubtedly preferences exist in each locality and can be determined by observation. From the practical standpoint, where heavy concentrations of deer occur, it would seem that the tree species available suffer the most and about in the degree of availability. It sometimes appears that deer prefer the plants which are exotic to the site—those that have been established artificially and perhaps furnish the deer something new and unusual for their diet. Exactly what influences deer in their food selections is not definitely known.

Mitchell and Hosley (1936) in an experiment where they applied nitrogen at different rates suggested tentatively that possibly the sugar content of foliage may be an influencing factor in determining browsing by deer. Food preferences are likely to be local and seasonal. Since the principal damage to the forest is done in the fall and winter, the forester is most interested in the kinds of food preferred at that time of year. Deer sometimes will nip off the buds as well as the foliage and small twigs of young trees within their reach.

Deer may cause complete destruction of the tree growth on an area, provided that this growth is so short as to be entirely within the reach of the animals. Hence reproduction is more seriously injured than older stands. Not only is existing reproduction destroyed but also its establishment on open areas may be prevented. Where older stands have live branches within the reach of the deer the branches may be entirely eaten off for distances as high from the ground as deer can reach. Normally this means to about 6 feet, a height to which deer can reach by standing upon their hind legs. When trees are bent down by the snow they may be injured at points which could not normally be reached.

In addition to the injury done by browsing, deer also cause some mechanical injury to trees through rubbing with their horns, barking small trees, and breaking the branches. Such injury is much less important than browsing and only in occasional places does it become of importance. Heavy browsing in some parts of the country is likely to

destroy the cover for a large variety of small game and in this way be an indirect cause of damage.

Where the number of deer are limited the damage they do may be inconspicuous and of no particular moment. The serious damage is caused when the area is overstocked with deer. Abnormal overstocking for a large region, however, is not requisite for the infliction of appreciable damage, since deer frequently eat heavily on restricted areas within their range, causing injury there, although at the same time other areas nearby may contain plenty of forage which is not browsed because the deer do not like to move from their accustomed range. The habits of deer as to food preferences and places for feeding need further investigation. In general, where heavy snows lie during the winter season, the greatest damage will be found to occur on warm southern slopes and in the bottoms of sheltered valleys.

In many parts of the country the numbers of deer are too small to cause serious damage except on occasional trees, but, as the problem is studied, overstocking is frequently found to occur either in restricted localities or over considerable extent of territory. Two well-known instances are the Kaibab National Forest (Anonymous 1931) and portions of Pennsylvania.

Just how many deer can be allowed in a given area without so overstocking it that severe damage results has not been definitely established. The figure will vary with the forest type and other factors. A stocking of 1 deer to 40 acres may be considered relatively safe as far as general damage to the forest is concerned, although even under such conditions it might be possible to have severe damage upon certain small areas. Where the deer were most abundant in Pennsylvania (Clepper 1931) the average stocking was 1 deer to 12.5 acres of forest. In these areas the damage caused was so severe as to have instigated a study of how best to reduce the stocking to a reasonable number.

Clepper (1931) considers that, although under Pennsylvania conditions 15 to 25 acres would support a deer, even with such stocking the vegetation would be so heavily browsed that inadequate food and cover would remain for small game.

Indirectly deer cause additional damage by taking some of the food which would be eaten by domestic animals, thereby reducing the possible stocking of such animals. In regions where the two types of animals eat different foods this point of course will not hold. However, the food requirements are sufficiently similar so that deer will eat a considerable share of the food which some types of domestic animal would consume. Grazing by domestic animals is generally a higher

form of land use than game management, and if interfered with presumably the revenues from the forest will be lessened and loss suffered in this way because of the deer.

The most satisfactory method of control from the standpoint of expense involved and effectiveness is to reduce the number of deer to a proper degree of stocking. Methods for doing this must be worked out in harmony with the game laws in each individual state. Liberalizing the hunting laws by extending the season, allowing the shooting of more animals, permitting does as well as bucks to be taken, and the abandoning of game refuges have all been suggested as means of obtaining the right stocking in areas now overstocked. The proper stocking will, of course, result in improving the health of the deer herd and in making hunting a better sport. Undoubtedly the average forest can carry a reasonable stocking of deer without suffering appreciable injury.

Aldous (1941) suggests that the northern white-cedar swamps in the Lake states be selectively cut in winter to furnish the browse needed by deer. The cutting should be done gradually as the deer need the browse, approximately 4½ pounds of cedar per day per deer. The ideal cutting pattern would develop small clearings ⅛ to ¼ acre in size spaced ¼ to ½ mile apart. For cedar to reproduce in the Lake states the deer must be excluded or maintained at a low number. Aldous considers protection of cedar by deer-proof fence too expensive. As the right solution, namely reduction of the deer herd, is opposed by public sentiment, presumably the cedar will disappear.

The point that proper stocking must not be exceeded if deer are to remain healthy can scarcely be overestimated in its importance from the standpoint of developing better understanding between sportsmen and the forest manager. Perhaps in respect to deer more than to other animals the sportsmen have believed that no limit should be placed upon their numbers. Many well-meaning people have taken this attitude, and they must be convinced that the reduction in numbers is an essential measure for the continued healthy development of deer. Without their cooperation it is questionable whether adequate reduction in numbers of deer can be secured in many parts of the country.

One of the principal reasons for overstocking with deer comes from the fact that predatory animals capable of killing deer have either been exterminated or are kept at such low numbers that their beneficial effect in thinning the deer herd is lost. Mountain lions, if not hunted too closely, will in the unsettled sections of the West go far toward keeping the deer down to a normal population.

Other methods of reducing the number of deer and keeping them at

a reasonable figure would be the building of more roads to make inaccessible areas easier to get at and thus encourage more hunters to go into them.

Besides regulation of the stocking, various special methods of controlling deer have been used to some extent in this country and abroad. They include such types of work as the erection, around areas being reproduced, of deer-proof fences too high for the deer to jump; the protection of the tops of young plants with repellent compounds such as tar, grease, and sulphur; or their protection by metal guards of various types intended to prevent the deer from biting the terminal shoots. All such methods are too expensive to be considered as practicable in forestry work, except under extremely intensive management. Clepper (1931) has found that lopped branches laid over the trees to be protected keep the deer from browsing where weedings in plantations are being made. This might prove an inexpensive method of lessening the damage. He also estimates the cost of fencing 7½ feet high with woven wire at $4.00 per rod.

Weiss (1940) found effective a repellent made of 1 part hydrated lime, 5 parts fresh cow dung, and enough water to produce a mixture of about the consistency of rather thin plaster.

BEAVER

Beaver are looked upon by many people as most valuable and interesting animals which should be encouraged as far as possible. From the standpoint of fur production this is undoubtedly true. In many parts of the country, beaver have already become extinct, and their number in most regions has been reduced so materially as to threaten extermination. Under the protection which beaver are now receiving in some areas, the danger of extermination is less imminent.

Beaver have had a beneficial influence in creating meadows and stopping erosion. Ruedemann and Schoonmaker (1938) conclude that "beavers are able to aggrade all smaller valleys below the size of navigable rivers. . . . The fine silt gathered in the beaver pools has produced the rich farm land in the valleys of the wooded areas of the northern half of North America."

Beaver, however, are not animals that can be encouraged without expecting severe injury to the forest. This injury is restricted, to be sure, to areas in the vicinity of streamways and ponds. In a well-watered section, particularly where the topography makes possible many slow-flowing streams, swamps, and ponds, the area subject to

beaver damage may approximate the entire forest area. In other regions of rough topography, beaver, even though present, may never be of appreciable importance as a source of damage. The average situation lies between these extremes, and usually damage affects only a small portion of the forest area.

At the present time beaver are relatively so scarce that the amount of damage caused in most forest areas is of small moment, yet on an area where they are abundant the injury they inflict may be of primary importance. For example, the damage within recent years to the black spruce forests in northern Minnesota has been severe (Hoene 1946). Beaver have been causing four types of damage to the forest in that region: seed germination is prevented, small seedlings are killed, standing timber is destroyed, and growth is retarded on trees in stands partly flooded. In 1 year the partial flooding of 10,000 acres is estimated to have cost the community more than $75,000.

The damage done by beaver consists in the girdling and felling of trees including many of merchantable size. A large number of trees are killed in this way in the vicinity of their ponds and dams. Certain species, particularly the aspens, are preferred.

Next to aspen, birch appears to be a favored food species. Softwoods such as hemlock, spruce, pine, and cedar are not so well liked as many of the hardwoods. Nevertheless the bark on these species may be eaten. Beaver cut a good many softwood trees, but usually the trees are neglected after being cut or some branches may be taken and added to the dam or beaver lodge (Johnson 1927, pp. 615–616). The principal food of the beaver consists of the bark of deciduous trees. The animals peel the bark from the larger pieces right where they are felled; the smaller branches may be taken away entire or gnawed into sections and transported to the feeding grounds. A relatively large amount of wood in the trees which they fell is not utilized by the beavers (Aldous 1938).

Beavers also eat buds and a variety of other herbaceous materials. They cut trees down primarily for food but likewise use portions of the trees in dam and lodge construction. They also store food for the winter, mainly in the form of small branches, in places near the beaver lodges or burrows where they can swim to it under the ice.

In addition to actually felling living trees beavers cause other classes of damage. They may destroy the entire stand adjacent to ponds by raising the water level, thus submerging the root systems of standing trees or at least increasing excessively the moisture content of the soil. The damage resulting from flooding is greater than that consequent

upon the girdling of trees. Their habit of raising the water level of ponds is also a source of damage to property around the ponds. Buildings may be flooded by the rising water, and areas of ground may be rendered more boggy.

As a remedy against damage caused by flooding, the beaver dams may be dynamited or torn out and the water level lowered. This is only a temporary remedy since the beavers are exceptionally active in rebuilding broken dams and again raising the water to its former level. A method of drawing the water from their ponds, by means of pipes with the ends protected, so as to reduce the water level to a desired point, has been suggested by Bailey (1927) as another method of control. To save trees from girdling the beavers might be fenced in or valuable trees might be surrounded at the base by wire fences. These last two measures are not practicable in forestry.

A reduction in number of the beaver by trapping or shooting is the only remedy that will reduce the damage appreciably. Unless income from beaver for fur or as a recreational asset is considered a valuable element in the land income, it will be advisable to keep the number of beaver very low or to remove them entirely from the forest area.

PORCUPINES

The porcupine where found in abundance is one of the most injurious wild animals in the forest. The porcupine has a widespread range through the northern and western portions of the country and feeds upon a great variety of trees. Fortunately, its distribution and the consequent damage are not uniform. The animal is concentrated on certain areas and virtually absent on others. In the Southwest the porcupine is relatively more abundant on cutover areas than in fully stocked forest. This is explained (Taylor 1935) by the greater abundance of herbaceous vegetation on the ground in the cutover areas. The diet of the porcupine is a combination of material from trees (inner bark and foliage principally) and herbaceous browse. During the summer, herbaceous vegetation is the chief source of food; when snow is on the ground the inner bark of trees is utilized. In the intermediate seasons both types of food are eaten. The porcupine prefers areas where both types of food can be secured.

Curtis and Kozicky (1944) working in Massachusetts and Maine found that porcupines will eat a great variety of food. Among conifers, hemlock foliage is preferred, and the inner bark of sugar maple is a favorite food.

The damage to the forest caused by porcupines consists in the biting-off of small seedlings, eating of foliage, and gnawing of bark on larger standing trees. The injury may occur on any part of the bole or on the branches since the animals climb practically to the tops of trees. When the bark is gnawed completely around the trunk the bole is girdled and a portion above the girdle dies. Repeated attacks result in deforming the tree. In many instances complete girdling does not result, but serious open scars are left on the bole or branches. The most complete destruction is caused where stands of young reproduction are attacked. Sometimes a large percentage of the stand on limited areas is ruined. The damage is greatest near the porcupine dens, which are most abundant in rocky country.

Where the forest on the more difficult sites is of an open character, as it may be on cutover and burned-over areas, and where reproduction is needed, the porcupine may actually threaten the continuance of the forest because of its continued destruction of reproduction and attacks on the trees furnishing seed.

The porcupine has no important beneficial function other than to add variety to the forest scenery. It has no value as a game animal except in emergencies and so far as known has few if any interrelationships with other members of the forest community. Mistletoe occurring on ponderosa pine in the Southwest is a favorite food of the porcupine, and Taylor (1935) mentions this as a possible beneficial influence of the animal. Usually the porcupine eats not only the mistletoe but also patches of the bark and furthermore may possibly assist in spreading infection of mistletoe.

The best method of control is killing the porcupines. No seasonal restrictions have been set upon their destruction. Mountain lions, bobcats, and fishers appear to be the chief natural enemies of the porcupine and undoubtedly would go far to effect control if they were themselves allowed to become abundant. It is, however, impractical to depend entirely upon this method of killing the animals.

Shooting is an excellent method of control when the animals are abundant and can be found easily. It has its greatest usefulness in winter when the porcupines spend most of their time in the trees.

The placing of a bounty on porcupines has been tried temporarily in some of the northeastern states. This will accomplish a reduction in number of animals where they are abundant but is likely to prove expensive.

The U. S. Fish and Wildlife Service has worked out a method of poisoning porcupines (Gabrielson and Horn 1930), experimenting

chiefly in Arizona. Two general methods of putting out poison bait were employed. In one, strychnine mixed with common salt was placed in rough wooden cups nailed to the trunk of the tree 8 or 10 feet above ground usually at a convenient height above a large limb so that the porcupine could sit on the limb while he fed from the cup. Investigation had disclosed that during the seasonal migration of porcupines they followed well-defined routes and certain individual trees were frequently visited.

This method of putting poison in selected trees has proved more satisfactory than the second method of poisoning, which consists in placing the bait in the porcupine dens. Unfortunately, poisoning is illegal in some parts of the country.

Hunting with trained dogs and trapping are other methods of control which have been suggested. Damage by porcupines, although often spectacular, may be considered a minor source of injury, except where the animal is abundant. On restricted areas close around the dens the forest may be badly deformed as a result of abnormally heavy feeding (Curtis 1941). These areas are a small fraction of the forest area.

Curtis (1944) appraised the accumulated damage on areas in Maine with a population of 20 to 28 porcupines per square mile and found the loss to range from 11½ to 36 cents per acre. This is considerably lower than reported in Colorado.

RABBITS

Rabbits cause injury by biting off buds, small branches, and stems, and gnawing the bark, often girdling the tree and causing its death. The damage is done by these animals during the winter months when other food is scarce and occurs ordinarily within 2 feet of the ground but above the duff.

In examining seedlings and trees which have evidently been gnawed by animals it is often difficult for the practicing forester to determine just what animal caused the injury. Each animal leaves distinctive tooth marks (Pearce 1947) which tell the expert the identity of the animal. The tooth marks of rabbits lie horizontally across the stem of the tree. Tooth marks are broad and individually are about 1/12 inch wide. Porcupines seldom eat from the base of a tree. Their teeth extend obliquely to the main axis of the branch, and the width of the cut by a tooth averages 0.10 inch. Red and gray squirrels eat the bark of maples and sometimes conifers. Their tooth marks are very narrow, about 0.01 inch wide, and occur in all directions.

Rabbits live principally on the bark and buds of woody vegetation during the winter. Rabbit damage is of rather spotty and local distribution, being very severe on areas frequented by them and not being found at all on other areas fairly close by. Rabbits are likely to gather in the winter time in stream valleys and on southern and western exposures where the herbaceous food is available until late in the season, and here, of course, the damage will be at a maximum.

Seedlings and small trees are chiefly affected. Fast-growing shoots are attacked in preference to slow-growing specimens. Often young seedlings recently released by a weeding are selected because of their more rapid growth rate. The rabbit has a wide choice of tree species for food. In the Lake states (Anonymous 1936) aspens, willows, and birches are said to be preferred species for food, but in the last analysis the trees attacked are those present on the areas where the rabbits are living at the time when food is scarce.

The most severe damage occurs in those parts of the country where rabbits are most plentiful. In other words, just as with the larger animals like deer, excessive damage from rabbits takes place on areas where the rabbit population is abnormally high. Under normal conditions of stocking, the rabbit, though doing damage each year, would remain an unimportant injurious factor. They are sometimes so numerous and so destructive as to prevent reproduction locally. Overpopulation of rabbits has been found to occur in cycles, the rabbits being reduced tremendously in number by the inroads of disease after reaching their peak of abundance.

Methods of controlling damage from rabbits must be sought largely through reduction of the rabbit population and attempting to keep it at reasonably low limits. All such methods as snaring, poisoning, trapping, and hunting should be used. As yet not enough of this work has been done systematically to give the satisfactory basis for predicting what may be expected from these measures.

The snowshoe hare has become a serious source of injury to plantations in the Lake states. These attacks are cyclic on about a 10-year cycle. To reduce the amount of injury it will be advisable to plant cutover, brushy areas and those near swamps in the low part of the hare cycle. During high portions of the cycle open, brush-free areas of several acres in size should be selected for planting (Aldous and Aldous 1944).

Repellent sprays applied to seedlings in the nursery or to the stock after planting are likely to delay injury temporarily but probably will not be effective after new growth develops.

Fencing would give excellent protection against rabbits but is too expensive for general use. Shirley (1941) estimates the cost of a 5-foot fence made of poultry netting using both 1-inch and 2-inch netting, with the lower 4 inches buried in a trench, at $400 to $500 per mile. It requires annual maintenance.

Hosley and others (1931) believe that the shooting of rabbits under the present game laws will suffice in New England to keep damage at an acceptable figure. Similar action in other parts of the country will not necessarily accomplish the same result.

SQUIRRELS

Squirrels eat seeds, fruits, and the buds of many trees. Buds are eaten either directly off the trees, both the side and terminal ones being destroyed, or from the small twigs which have first been cut off. Bark may be eaten and stripped off in quantities sufficient to girdle the tree stem. The Richardson red squirrel has been reported girdling young conifers, chiefly western larch and lodgepole pine in Idaho (Stillinger 1944).

Pike (1934) reports squirrels girdling the main stem 10 to 20 feet from the top on ponderosa pine trees 4 to 7 inches in diameter breast high.

Hatt (1929) in his study of the red squirrel lists a large number of tree species upon which the squirrels feed. The eating of seeds is most damaging to the forest since it directly affects the amount of reproduction. The squirrels in many places are so numerous that they devour practically all the seed crop of certain species. The heavy-seeded trees such as the oaks and hickories are especially likely to suffer in this way. The consequence is that squirrels often exert an important influence against the establishment of reproduction. Sometimes it seems impossible that any reproduction can start on account of the large number of squirrels in a given forest. The effect of squirrels upon reproduction is not entirely an injurious one, since oftentimes they store seeds in the duff which are overlooked and which later germinate and establish reproduction. Undoubtedly the distribution of some of the heavy-seeded species is helped by the practice of the squirrels in taking the seeds from these trees and carrying them some distance before hiding them in the ground.

Seeds may be eaten immediately or they may be stored and even carried over winter in storage. This storing of seeds by the squirrels is sometimes of benefit to seed collectors, particularly in parts of the

western states where the squirrels have the habit of making sufficiently large caches of conifer cones to make it worth while for the collectors to find them.

Smith and Aldous (1947) list 28 species of squirrels and chipmunks as eating forest tree seeds.

On the whole, the injurious influence of squirrels far outweighs any beneficial effects they may have in aiding reproduction. Hosley and others (1931) consider the squirrels particularly injurious to the conifer plantations made in New England. Such quantities of the buds are eaten that the trees may sometimes be deformed and at least have the growth rate lowered. Squirrel damage is quite local in its most severe phase, but the distribution of these animals is general and some injury can be found in almost every forest.

The hunting of squirrels should be encouraged as a control measure, and with some of the species which are not edible trapping with bait is suggested as a practical means of reducing the numbers.

Lynx and bobcats are considered enemies of the squirrel, and possibly certain other predatory animals feed upon them. It is doubtful whether control against serious damage by this animal can be secured in settled sections of the country through dependence upon predatory animals.

MICE AND OTHER SMALL RODENTS

A common type of injury from mice and other small rodents is the destruction of tree seed. Sixteen species of small mammals, other than squirrels and chipmunks, are listed by Smith and Aldous (1947) as feeders upon tree seed. Feeding takes place throughout the forest, as well as in nursery seedbeds. Besides eating tree seeds, mice may cause serious injury to seedlings and young trees by gnawing the bark either above or below ground, often girdling them and causing death. The tops of seedlings may be bitten off. Perhaps the most common type of injury occurs right at the ground line under the forest litter where it is not noticed until after the next growing season when the brown foliage and dead branches indicate that the tree has been girdled. Injury of this type is caused by the mice during the winter time, particularly under deep snow when their food supply is scarce.

Mice are most abundant in grass-covered areas with a sunny aspect. They appear to increase by cycles and to cause serious damage periodically rather than each year. Sometimes the injuries to standing trees are sufficiently serious to cause the death of a large portion of the trees

in the stand. Eastern hemlock is a favorite with mice and should never be planted on grass-covered fields where mice are abundant.

Littlefield, Schoonmaker, and Cook (1946) describe serious damage to conifer plantations by the field mouse. Scotch pine and Douglas-fir were highly favored by the mice. Norway spruce, white, red, and jack pines, northern white-cedar, balsam fir, and larches were slightly favored. White spruce was not attacked.

Methods of control should rely to a considerable extent upon the natural enemies of mice. Predatory birds such as hawks and owls, and predatory mammals like foxes and weasels, if present in the right numbers will tend to prevent an excessive development of the mouse population. Where fields covered with heavy grass are to be planted, burning over the area just before planting will reduce or drive away the mice.

In general, direct control in the forest is impracticable, but in nurseries intensive methods of combating mice are warranted and can be applied successfully. For this purpose poisoning is considered the most satisfactory. Poisoned bait should be kept out in nurseries through the greater part of the year. This bait, usually cereal grains poisoned with strychnine, should be placed in receptacles into which mice can enter, but not birds or larger animals. This intensive type of poisoning can be afforded in nurseries but not on cutover areas being regenerated. In some Douglas-fir stands in the Southwest mice have prevented the establishment of satisfactory reproduction. Krauch (1945) suggests that, when good seed years occur, cutover areas should be systematically poisoned with thallium sulphate applied to sunflower seed as bait. At the present time thallium sulphate apparently is the only satisfactory chemical for poisoning areas which are to be either naturally or artificially reproduced.

Although mice have been looked upon as having only an injurious influence on the forest it is true that they may exert minor beneficial influence. Graham (1928) considers that mice render assistance in controlling the larch sawfly by opening the cocoons if they are located on better-drained sites. The tunneling constantly carried on by mice and other small rodents acts as a sort of cultivation thereby improving the tilth of the soil.

Hamilton and Cook (1940) stress the beneficial influence of small mammals, in which classification they include mice, moles, shrews, chipmunks, and flying squirrels. In their opinion these animals are more effective than birds in controlling insects, because they are far more numerous and are active the year around. The additional bene-

fits conferred are loosening and mixing soil by their burrowing, helping to carry air and water below the surface, carrying leaves and other debris into the soil, and helping support the larger predatory animals.

In the western United States pine squirrels, chipmunks, and a mouse have been seen eating the bark of white pines attacked by the blister rust disease (Mielke 1935). Probably other animals also eat this bark. The eating, which is for the purpose of getting the fungus and the starches formed in the bark, occurs during the late winter, and frequently it may result in a considerable reduction in the volume of spores, capable of infecting *Ribes* plants, which might be released by the diseased pine trees.

Usually mice because of their abundance and almost universal distribution consume more forest tree seed than the other small mammals grouped with them. Moore (1940) found this to be true in the Pacific Northwest.

Small rodents other than mice affect the forest in a somewhat similar manner and can be included with mice. Although it might be possible to reduce populations of mice and small mammals by inoculating them with virulent diseases this would be too dangerous a method of control to use, since other animals and man would be found susceptible.

BIRDS

The beneficial influence of birds in destroying insects and small rodents far outweighs their injurious effects upon the forest (McAtee 1926). Nevertheless, in several respects they are a source of damage to the forest. Birds feed upon the seeds of forest trees and bite off the tops of seedlings. A list of 37 species of birds eating forest tree seeds is given by Smith and Aldous (1947). Woodpeckers and sapsuckers peck holes in the trees. Birds occasionally injure the forest by roosting in the tree tops in such large numbers as to increase appreciably the nitrate nitrogen content of the soil. Such injury becomes of consequence only when the birds are gathered in flocks and have the habit of roosting each night in the same place for a considerable period of time. Where this happens the forest is injured in several ways. The trees may be killed by the effects of too high a concentration of mineral nutrients, particularly of nitrate nitrogen in the soil, or the mechanical effect of the roosting birds may prove injurious to the foliage of the trees.

This is probably of greater importance to conifers than hardwoods. As a matter of fact, injuries so far reported from roosting birds have

been in plantations of conifers. Young (1936) reports starlings as responsible for injuries of this type, and Stewart (1933) describes a case where a flock of blackbirds seriously injured a pine plantation.

Cook and Littlefield (1945) report grosbeaks feeding on the buds of conifers. These birds eat out the center of the bud, whereas red squirrels, to whom similar injury is sometimes attributed, bite off the twig cleanly just below the bud cluster. Grosbeaks also attack hardwood buds.

Among the beneficial effects of birds may be classed their feeding upon a wide variety of insect pests and also upon small rodents which are injurious to tree reproduction. Birds are an important agent in disseminating the seed of many tree species, particularly those with fleshy fruits. On burned-over lands, birds may play an important part in the natural reforestation of the area by bringing in seeds from outside the burn (Adams 1923). Since birds have such important beneficial effects, it is often a question whether anything should be done to control their depredations.

On the whole, birds should be protected and encouraged to increase in the forest rather than be reduced in numbers. In the forest the damage which they do can hardly be lessened without destroying the birds, and this, as already stated, is undesirable. The injury done to seeds and seedlings is most noticeable in nurseries. In such localities direct control can be undertaken without injury to the birds. The methods usually employed are protection of the seedbeds and seedlings in their young stage by a cover of wire netting. Seedlings are attractive to birds principally during the stage when the seed coat is borne on top of the small plant. As soon as the leaves have cast off this seed coat, injury of this sort from birds is largely at an end.

Stewart (1933) reports that roosting birds can be driven away by repeated shooting, and, where large flocks of birds are found to be nesting in valuable areas of forest, it should be practicable to use this method for driving them out.

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CHAPTER 19

Protection against Atmospheric Agencies

GENERAL CONSIDERATIONS

A variety of agencies affecting plant life are included in this chapter. They are largely the effect of natural phenomena such as heat, cold, precipitation, and wind. These natural factors exert both a beneficial and an injurious influence upon the life and growth of plants. Most atmospheric agencies when acting in normal manner are essential for tree growth. A plant must have water and a certain amount of heat for its growth, and, when these factors are secured in the proper measure, the plant grows most rapidly. When, however, one or more atmospheric agencies are either present in an abnormal amount or lacking in the desirable quantity or when they so operate as to affect trees in an unusual manner, the results upon tree growth and development may be injurious rather than beneficial.

It is impossible to control or change the atmospheric agencies themselves for climate is beyond the control of man. He cannot change the essential features of climate, which in a broad way expresses a summation of those points which are usually included under the term atmospheric agencies. Since the factors themselves which influence tree growth and development cannot be altered, the only recourse for the forester is to so manage his forest as to obtain the most favorable reaction of the atmospheric agencies upon its development.

As a consequence of the wide range in values of a given atmospheric factor which may be experienced in a given place, a certain amount of loss from natural atmospheric factors should be anticipated as inevitable in all forest crop production. The extent and character of such a loss can be modified and partly controlled by proper methods of management. Prevention in this case, then, is not so much the elimi-

nation of the occurrence of dangerous climatic influences as it is the developing of the forest into such a condition, and its maintenance in this condition, as will prevent or minimize the injurious effect of the climatic factors.

Poisonous gases and smoke cast into the atmosphere are largely within the control of man and can be prevented by regulatory measures. They differ in this respect from the other atmospheric agencies here included. It might even be questioned whether they should be placed here along with such factors as precipitation and heat, since they are not directly a part of the natural climate. However, smoke and poisonous gases in the air are certainly a part of the atmosphere, and, even though they are produced as a result of man's negligence, they should be classed and considered among the atmospheric agencies against which the forest needs protection.

In addition to the direct effect upon the forest which atmospheric agencies exert they may have serious indirect effects through weakening of the individual trees, and thereby encouraging the entrance of fungi and insects.

Atmospheric factors include a number of independent subjects, each of which is discussed separately. Though this treatment is advisable in studying the subject, yet actually the atmospheric factors do not act independently of one another. They are intimately interrelated, and as the forester contends with them in practice he finds that their effect is a combined one in which the influence exerted by a given factor is oftentimes difficult to measure accurately.

Trees which have been grown under conditions prevailing in a closed stand are more easily affected by atmospheric factors than trees which have been grown in a relatively open position. The latter have more symmetrical, deeper, and more luxuriant crowns which act as a sheltering cover to the tender parts of the stem and branches. Trees grown in an open position have been accustomed by long exposure to be resistant to atmospheric influences. The individual trees in a closed stand when opened up by the removal of several of their associates are exceedingly vulnerable, as their crowns come only part way down the trunk—often less than one-quarter of the total height—and leave a long, slender, bare stem exposed to the atmospheric elements.

Forest crops, of course, must be grown in closed stands, and it is desirable that the lower portion of the tree trunk should be free of branches. Granting these facts, it is evident that careful attention must be given to protecting forest-grown trees from injurious atmospheric agencies.

The classification of the atmospheric factors affecting forests injuriously, as arranged for the purposes of this discussion, includes:

Temperature so high as to injure plant tissues.

Frost (temperature injuriously low).

Drought or a shortage of water available for the tree.

Water in excess of that required for the proper development of the tree. Under this heading are included such manifestations of an excess of water as floods, landslides, and erosion as far as such soil movement is occasioned by water; frozen water in the form of snow, ice, hail, and avalanches, the last being the movement of water in a mass of snow and ice.

Wind in its various manifestations, among which are included drifting sands and erosion as far as caused by the wind movement of soil.

Lightning.

Poisonous gases and smoke in the atmosphere.

HIGH TEMPERATURES

High temperatures may result in the death of small seedlings and in injury to sensitive portions where tender bark is exposed in trees of all sizes. Fire furnishes a special example of overheating, but otherwise temperatures excessive for forest trees are produced by heat of the sun. Such injuries occur chiefly on the southern and southwestern sides of the tree.

Excessive temperatures beyond the maximum suitable for a given tree are frequently encountered on open areas. Hence, the greatest effect of excessive heat is felt by young reproduction. Different investigators have secured slightly different results as far as lethal temperatures are concerned. They all agree, however, in considering temperatures above 150° F. fatal to young plant tissues. As temperatures above 160° F. are frequently experienced at the surface of the ground and in the top soil layer, reproduction may be entirely prevented on such areas.

Both Bates and Roeser (1924) and Baker (1929) show that the maximum air temperature may be the climatic factor preventing the survival of small seedlings and thereby making natural regeneration impossible. Excessive heat causes stem lesions close to the surface of the ground, where the temperatures are the highest, or sometimes in the top soil itself.

Heat lesions on seedlings frequently have been mistaken for a similar type of injury caused by damping-off fungi. The two should not ordi-

narily be confused. Hartley (1918) shows that the damping-off fungi spread progressively upward and downward, whereas the heat lesion usually is definitely limited to one spot for some time, the upper stem and cotyledons remaining turgid. The heat lesions are often found only on one side of the stem, and this the southern side. Sometimes seedlings may recover from heat lesions. As seedlings advance in age, the bark becomes thicker and they are less exposed to the effects of excessive surface temperatures. Plants up to several years in age, however, may be injured, particularly if the stems stand at such an angle as to be perpendicular to the rays of the sun.

Transplants either while growing in the nursery or after having been set in their field location may suffer death from excessive heat. Korstian and Fetherolf (1921) carried on experiments in Utah with Engelmann and Norway spruces and found a significant difference in the percentage of trees killed by excessive heat among transplants whose stems inclined toward the north as contrasted to those whose stems inclined toward the south. The tops of the trees shaded the stems inclined toward the south from the direct rays of the sun and hence the injury from excessive heat was small, whereas those inclined to the north had fully exposed stems nearly perpendicular to the rays of the sun and suffered heavy loss.

Shirley (1936), working with white, Norway, and jack pines and white spruce in the Lake states, found recovery after heat injury to seedlings to be dependent upon their ability to send out epicormic branches from the stem, below the point of injury. White pine exceeded the other species in ability to send out epicormic shoots. Jack and Norway pines were deficient in this respect. There was little difference between species in ability to withstand heat.

The injury known as sunscald is sometimes attributed to high temperatures. It is usually found among older trees in places where a dense stand has been opened on the south or southwest side and certain portions of the trunks of the trees which had previously been densely shaded are now left exposed directly to the sun. Where this situation occurs the cambium under areas of thin bark is likely to be killed. The areas of dead tissue may be confined to small spots or may extend in a continuous strip for several feet along the stem of the tree.

This type of injury appears to be caused not by temperatures high enough to kill plant tissues but rather by the action of sun and low temperatures on bright cold winter days (Huberman 1943). The sun warms the plant tissues in late afternoon, and after sunset a rapid drop in temperature kills the plant tissues by freezing (see page 285).

Control Measures

Injury from excessively high temperatures can be avoided in forest nurseries by furnishing the tender seedlings with the requisite amount of shade. Natural reproduction on areas being regenerated may need shelter the first year or two of its life. Frequently it will be practical to provide such shelter by making partial cuttings instead of removing all the old timber at one time. Where severe loss to young seedlings is anticipated from excessive temperatures on cutover areas, cuttings of the shelterwood or selection types may be needed. In some situations it may be necessary in order to secure adequate natural regeneration to make the cuttings of a strip character, advancing in direction toward the sun. Reproduction would be expected on the sheltered side of the stand away from the sun.

Among the most difficult situations upon which to establish natural reproduction are the south and southwest exposed edges of an old stand. Here the young seedlings not only must endure severe root competition from the neighboring old trees, but they also are exposed to excessively high temperatures at the ground surface along the edges of the old stand. Observation in many places will lend support to the statement that reproduction tends to be better on the northerly than on the southerly edges of an old exposed stand, owing primarily to higher temperatures on the southern edge. Clearcutting or even heavy partial cutting on the south side of stands being reproduced should be avoided, wherever the climate makes excessively high temperatures possible and the species grown is sensitive to this factor. Based upon a study made in Greece, Moulopoulos (1947) concludes that planting using coniferous stock not less than 0.15 meter (5.85 inches) tall and so planted as to shade the stem is the only method indicated for successful reforestation technique in hot and dry countries.

Similarly, to prevent injury to the trees in older stands from sunscald, or bark-scorching, as it is often designated, exposure on the southern and western sides of trees and stands, which previously have been densely grown and are susceptible to the injury, should be avoided.

On areas being artificially regenerated where high temperatures sufficient to kill the planted trees are expected, it may be best to plant the trees with their stems inclined toward the south and thus secure the benefit of the top in shading the stem. Planting the trees on the northeast side of logs, stumps, and rocks will serve to furnish some protection from the sun and is likely to increase survival.

FROST

Trees may be injured in various ways or even killed outright by low temperatures. The injurious effects of low temperatures upon trees may be classified into four groups as follows: injury from late frosts in the spring, injury from early frosts in the fall, injury during the winter, and frost heaving.

The most commonly noticed effect of low temperatures is the killing of new terminal and side shoots and tender foliage by the action of late spring frosts coming after growth has begun. Such injury may be quite local and restricted to small areas or frost pockets with poor air drainage or may be general over large areas. A striking example of the general type of injury, which damaged the beech throughout the eastern United States, took place in May 1936, as a result of a heavy frost. Foliage and new growth on beech trees of all sizes were killed. Small trees under older timber suffered as well as those standing in the open.

New growth on many conifers is likely to be killed by late spring frosts whenever they occur.

Late spring frosts cause serious interference with tree growth, since they catch the new leaves, twigs, and buds at a time when they are succulent, tender, and without the protecting woody tissues developed later in the season. Consequently all the new growth may be frozen and the tree forced to put out new foliage before it can go ahead with its growth for the season. Evidences of frost injury may be wilting followed by discoloration and dying back of the affected shoots and leaves.

Frost injury often results, on both conifers and hardwoods, in a forking of the main stem when the terminal is killed and more than one lateral survives. This type of injury is particularly serious in plantations not yet closed. Crooks are produced when a terminal is killed or a frost canker is made on the stem. Sometimes frost injury results in partial defoliation.

Frost may be responsible for changing forest composition in some places, particularly in transition zones between forest regions. Mesavage (1939) reports in northern New Jersey serious injuries by a late spring frost to oaks, locust, sycamore, yellowpoplar, and hickory—all species of the central hardwood forest—while black cherry, sugar maple, bigtooth aspen, yellow birch, American elm, basswood, and beech—northern forest species—were not affected.

Frosts coming early in the fall, before the current season's growth has become sufficiently lignified to withstand cold, cause injury similar to that resulting from late spring frosts. The damage is not so serious since the foliage and shoots are less succulent and more woody. The result is mainly a loss of a portion of the growth which took place during the year. Injury from early fall frosts is experienced most frequently by young plants which for some reason have continued vigorous growth abnormally late in the season. Stump sprouts and nursery stock too liberally fertilized suffer especially from early fall frosts.

Plant tissues endure without injury much lower temperatures during the dormant period than they are able to withstand in the growing season, yet they may be injured by periods of extreme winter cold. A type of frost injury, termed "winter killing" or "red belt," is the result of thawing during the cold winter season which induces transpiration of water from the foliage. Since the trees cannot at this season replace the water transpired with a supply drawn from the frozen ground, they suffer from drought. Such injury occurs only to conifers. Hardwoods not bearing foliage during the winter are not subject to injury of this type. Low temperatures in themselves are evidently not entirely to blame for injury caused by winter killing, as other climatic factors are involved. Sunscald, described on page 282, is now considered a winter injury and attributed to the rapid freezing of cambial tissues which have first been warmed by the late afternoon sun.

Roots of small trees may be killed by freezing in the winter, especially when growing in wet soils.

Another effect of winter cold usually seen every year is the production of frost cracks. This injury results from freezing of the stem in which tension is set up causing splitting in a vertical plane from the bark toward the pith. These frost cracks are likely to open year after year. Wind may be partly responsible for the continued existence and enlargement of frost cracks, particularly on dominant trees with exposed crowns. A callus growth is stimulated on the two outer edges of the forest crack, and in the effort to heal over the crack a protuberant ridge is produced running vertically up and down the tree. This ridge is plainly seen from the outside and usually starts at or near the ground, often in the hollow between two large roots, and extends upward for several feet. Sometimes frost shakes, or circular cracks, are produced. The result of either type of injury is to render the section of the trunk affected less valuable for lumber than it otherwise would have been. The extent of the damage depends on the skill of the sawyer in sawing the log.

Broadleafed species of trees, especially oak, elm, and ash, because of their wood structure, are more subject to frost cracks than the conifers. Large trees placed in a free position are considered more subject to frost cracks than those in a closed stand. Kienholz and Bidwell (1938) in a study made in Connecticut found scarlet oak, black ash, black oak, and red maple to be the species most frequently cracked. Most of the frost cracks were in the first 8-foot log, and more were on the sunny (south and west) sides of the trees than elsewhere, presumably because of the greater range there in temperature changes. The larger and dominant trees were more often cracked than smaller and lower-class trees.

Frost heaving, another type of injury attributed to low temperatures, results in damage of a mechanical nature to the roots of young plants. In the process of frost heaving, ice crystals form in the soil and raise both soil and plant, pulling the roots of the plants upward from unfrozen soil below or breaking the roots (Haasis 1923). When the soil thaws it falls back and leaves the plant roots partly exposed. When this alternate freezing and thawing of the soil is repeated numerous times, as may happen on exposed sites in many parts of the country, the plant ultimately is left lying on top of the soil and may be destroyed. Injury from frost heaving is particularly bad in regions where there is not an adequate covering of snow during the winter. Trees planted in the fall on bare soil are very susceptible to frost heaving, as their roots have not had time to develop a deep, firm anchorage. Shallow-rooted species are more easily heaved out than deep-rooted trees. Heavy and wet soils and sunny aspects, where alternate freezing and thawing is characteristic, are subject to frost heaving.

Another effect of frost heaving which has been observed (Tryon 1943) is girdling of small seedlings by the frozen soil. In the heaving process the frozen soil pushed up the stem may slide the bark and cambial tissue up the stem causing a girdle usually ¼ to 1 inch above the soil surface.

An indirect effect of low temperatures upon trees is the creation of wounds which may serve as points of entrance for fungi and insects. In some species this may prove a serious matter.

Frost injury may occur in all regions where the air temperatures go below the freezing point of water (32° F.). Within a given forest area there are likely to be small areas, termed frost pockets, of depressed topography, such as the potholes in glaciated country, where the cold air settles with a consequent large amount of frost injury. These frost pockets if cleared of their forest cover are difficult to restock. Frost

pockets sometimes may be created artificially by unskillful treatment in reproducing a mature stand. The trees on valley bottoms and lower slopes are more likely to be injured by low temperatures than those on upper slopes and ridges. Oftentimes small differences in topography result in widely divergent amounts of frost injury.

The net result of frost injuries as far as forest crop production is concerned is a decrease in growth rate and a weakened condition of those trees that are not killed outright. Species indigenous to a relatively warm region, when introduced into a colder climate, suffer severely from low temperatures.

Control Measures

Injury from low temperatures is difficult to avoid or even effectively minimize except by intensive and skillful management of the forest over a long period of time. Even then a large proportion of the damage cannot be prevented. Since frost, at least those types of frost injury that are sometimes susceptible of control, affects young plants principally, it follows that the efforts of the forester as concerns frost control should be directed toward safeguarding reproduction.

Nothing can be done to prevent losses from the exceptional periods of winter cold, but sensitive species which need shelter in early youth can often be protected against late spring and early fall frosts and against frost heaving. Fortunately not all the commercial species in the United States are sufficiently sensitive to frost to require protection.

Where natural regeneration is relied upon, the only feasible control against early and late frosts is to apply a partial-cutting method rather than clearcutting in removing the old timber. The shelter of the old timber oftentimes will protect the young seedlings. That this is not always true was shown throughout northeastern United States by the frosts of May 1936, which proved disastrous to beech reproduction under old timber, even when no cutting had taken place, as well as in the open. Special care should be taken in frost pockets or in low-lying level country subject to frosts not to expose reproduction until it is 3 to 6 feet in height, after which time it should be fairly well above the worst frost line. A frost pocket once cleared of timber is difficult to restock. A strip-shelterwood system advancing toward the south or southeast gives reproduction the most thorough protection against frost.

Where artificial regeneration is employed better protection is possible. In the first place, nurseries should be established only on sites

relatively free from frost injury. Hardy species and races of these species which begin growth late in the season should be chosen for reforestation on sites subject to frost. A race which starts growth late in the season will usually avoid injury in late spring frosts.

Seedlings in the nursery can be protected by covering during the winter with a variety of materials such as leaves, straw, or burlap and if necessary during the early spring with lath screens and burlap. Where planting is done in frost pockets, strong transplant stock as tall as can be economically handled should be used to get the plants above the frost line as soon as possible.

Where the danger from frost is great and the species wanted on the site is frost sensitive, it may be necessary to plant first a crop of fast-growing frost-hardy trees and later establish beneath this nurse crop the species wanted in the final stand. This is too expensive a method for general use.

Injury from frost heaving can be lessened by keeping all sites subject to heaving completely stocked with the densest possible soil cover. In planting dangerous sites, methods which do not leave the bare soil exposed should be employed. Planting should not be done in the fall, and only deep-rooted species and large-sized planting stock should be used. Sometimes drainage of wet soils may be worth while, both to lessen the frost heaving and to improve the rate of growth.

Practical methods of securing protection against the formation of frost cracks are as yet unknown. It may be that maintaining a good understory close around the best trees will lessen the damage from this source of injury.

DROUGHT

Drought may be defined as a deficiency of soil moisture. A shortage in the normal precipitation, particularly at the time of year during which plants are growing rapidly and consequently require the most water, is the primary cause of drought. Danger from drought is made more acute by atmospheric conditions such as clear days, high temperatures, low relative humidities, and strong winds, all of which stimulate a high rate of evaporation, thereby rapidly reducing the already scanty supply of soil moisture.

In nearly all regions the annual precipitation is subject to considerable fluctuation. Occasionally a year of abnormally low precipitation occurs, resulting in a serious deficiency of soil moisture. Where the precipitation falls to half or less of the normal, dangerous drought conditions are created, especially if the deficit comes in the growing season.

From the standpoint of damage to trees the fluctuation in total annual precipitation is less important than shortage of precipitation during the growing season. The distribution over parts of the growing season may have pronounced effect.

For example, in the Lake states (Anonymous 1935) a wet spring in 1933 was followed by a warm, early summer. As a result trees produced long succulent shoots and had no chance to develop resistance to drought. Then followed a July-August precipitation lowest on record with disastrous results to young trees. The following year, spring was drier than normal and consequently trees had short shoots. Although the total precipitation was less, no monthly total was as low as during 1933 and the result was better survival.

Lack of sufficient water to provide for the needs of the forest results in extensive injury. The extent of the damage ranges from a slight diminution in growth to the death of the tree. Stickel (1933) in studying damage from the 1930 drought in Connecticut recognized three types of injury. The first was injury and killing of ground cover and reproduction. These plants, being rooted in the upper soil layers, are affected first and most severely. As the drought increases in duration and intensity, the main stand itself with roots extending below the upper soil layers suffers injury, and trees even of large size are killed outright. A third type of drought injury is reduction in the growth rate, not only of trees having branches killed by drought but also of trees showing no external injury. Stickel (1933) found growth after the 1930 drought reduced approximately one-third.

Wilting is one characteristic sign of injury by drought exhibited by foliage and tender stems, although of course not all wilting is caused by drought. Yellowing of the foliage and premature shedding of leaves may be other symptoms of drought. In later stages particularly where the reproduction and lesser vegetation have been killed, a drought-affected stand often has the appearance of a burned-over area.

Sometimes entire groups of larger trees are killed by drought, but usually some individuals are killed while others close by, apparently growing under similar conditions, remain alive. Presumably restrictions of the root system due to underlying rock result in different soil moisture supplies (Hursh and Haasis 1931). Where precipitation is abundant and well distributed throughout the growing season, injury from drought, though it may affect some of the weakest plants because of the competition of the stronger individuals, is of no practical significance. The greatest losses from drought come when prolonged and severe shortages in the normal precipitation take place.

Spaulding (1946) reports as not unusual the dying of beech in the northern forest from a combination of summer drought and excessive winter cold. In Pennsylvania forests, chestnut, red, and white oaks are relatively drought-resistant trees, while scarlet and black oaks are much less resistant. Conifers, particularly eastern hemlock, are less resistant than the hardier oaks (McIntyre and Schnur 1936).

The amount and distribution of the precipitation are the major factors in determining the character of the forest. The tendency is for the stand to be as densely stocked as the water supply allows. Any pronounced decrease in the supply of water for a specific forest will be reflected in drought injury to the trees, particularly on thin soils and in regions where the normal precipitation is itself near the minimum for support of a forest. When a drought occurs, the forest on such areas may be killed outright, especially if composed of large old trees.

The most serious losses from lack of water result from subnormal precipitation in the growing season, but another manifestation of water deficiency is the reddish discoloration of foliage of conifers in late winter and early spring, often spoken of as winter killing or red belt and already mentioned as an effect of low temperatures. This injury results from transpiration by the trees during unusual thawing periods in the winter when the ground and trunk of the tree are frozen. Water to replace that transpired cannot be secured, and the foliage and twigs are injured or killed. The injury may be severe enough to kill the tree, or only a decrease in growth may result. Only species that retain their foliage during the winter are affected.

The indirect effects of drought are important. In addition to reducing growth, which has already been mentioned, drought has a weakening effect on the vitality of trees, making them more easily attacked by fungi and insects. The wounds created by the killing of parts of the trees offer convenient means of entry to these pests. Drought is frequently the underlying cause for damage by other injurious agencies. Hawboldt (1947) considers drought conditions extended over a 25-year period an important factor in the present alarming mortality of yellow birch in Nova Scotia. Secrest, MacAloney, and Lorenz (1941) attribute the heavy mortality in hemlock on the Menominee Indian Reservation in Wisconsin to drought as the primary cause, with the shoestring root rot as a secondary cause along with the eastern hemlock borer abundant only in dying trees. The evidence proved that the borer could not successfully attack healthy trees and succeeded only in trees with less than 60 per cent of their main lateral roots alive.

Control Measures

Drought injury cannot be prevented, but the extent of the damage can sometimes be minimized by proper methods of management. Effort should be made to put the forest into such condition that it can endure without serious loss the occasional seasons of deficient moisture. The principle that should be followed is to maintain a more open forest than nature would provide on areas where drought injury is feared.

Thinnings should be employed systematically, and a few vigorous stems with room for good crown expansion should be grown, instead of a large number of relatively weak competing trees. Observation has shown that less loss is experienced in thinned than in similar unthinned stands. Caution is needed not to make the thinnings so heavy that wind movement and consequently evaporation are seriously increased.

When stands are reproduced in regions of low precipitation, partial cuttings may assist in protecting reproduction from moisture deficiency. Shirley (1934) advances this idea for the pine forests of Minnesota. Here, the remaining portion of the old stand by shading the reproduction retards transpiration and hence conserves soil moisture in a region of low rainfall where evaporation losses are serious. The same idea may be applied in artificial regeneration, on sites especially subject to drought, by planting the trees in spots like the north side of a stump or log or under a light cover, where they will be shaded and somewhat protected from excessive transpiration.

The rotation for forest crops on dry shallow soils, to avoid heavy loss from drought, should be relatively short, and drought-resistant species should be favored in managing the crop.

WATER IN EXCESS

Under this subject is included the injurious influence which water in excessive quantities exerts on the forest. The influence of water on the forest is beneficial when present in proper amount. Water is an indispensable element for tree growth and is one of the most important factors in determining the productiveness of the forest site. The harmful effects of water come entirely through an abnormal supply: either there is a deficiency, when injury to the forest results from lack of water (this effect is termed drought and has been covered in a pre-

vious section), or there is an excessive amount of water, which is the condition here discussed.

For the purpose at hand, injury from excessive supplies of water will be considered under the following headings:

Violent rainfall.
Floods.
Erosion (so far as caused by water).
Landslides.
Frozen water in the form of snow, ice or sleet, and avalanches.

Violent Rainfall

Nature provides precipitation at irregular intervals and frequently supplies it for short periods of time in the form of heavy downpours. Violent rainfall in the act of falling may tear or strip off the tender foliage of trees. However, precipitation itself is rarely so violent as to cause serious mechanical injury of this type. Usually injury from violent precipitation is caused not by the falling of rain alone but by the action of wind, which is primarily responsible for the injury. Damage from wind is discussed on page 309.

Floods

The greatest damage to the forest from water in an excessive supply occurs after the water reaches the ground and is made possible by factors which allow and encourage its collection in a large volume. Water so collected is designated as a flood. Not every violent rainstorm necessarily results in a flood. Topography and geological structure are important factors in governing the possibility of floods. The forest floor and soil may be so porous as to absorb all the precipitation as it reaches the ground, thus preventing abnormal surface runoff which is the necessary forerunner of a flood.

Storms of exceptional length, a series of less severe storms, or a single cloudburst, may overtax even a dense forest, with the most efficient litter and soil for hastening percolation, so that abundant surface runoff occurs and a flood results. This was the situation in the Vermont flood of 1927. Unfortunately, a large share of the precipitation in most forest regions falls on land put to other uses than growing trees, or upon forest areas not fully effective as storers of water, and

consequently heavy surface runoff is the rule, and floods of greater or less volume are of frequent occurrence.

So far as the forest itself is concerned, the damage from floods which originate within forested areas is not of serious injury to these forests unless they have been badly managed. The principal flood damage to timberlands occurs in forests lying not on the headwaters of streams but on areas farther downstream and especially on watersheds which are to an appreciable extent nonforested on portions of their upstream areas. Ordinarily a flood to cause severe injury to the forest must arise on the watershed above the forest injured and then sweep down through that forest.

Flood damage to the forest is of varied character. Where the movement of water is violent young plants may be destroyed, trees may be torn out by their roots or broken off, and they may be wounded by the impact of ice, stones, and other materials borne along by the flood waters. The soil in which the trees grow may be washed away, or conversely, in lowlands where the movement of the water is slow, deposits of soil, rock, and debris of various kinds may be spread over the forest floor. Where such deposits are thin and made up of fertile soil of fine texture this effect of the flood may be beneficial. Where coarse material is deposited and the layers are deep, the effect is distinctly harmful.

One of the most characteristic and most disastrous effects of floods is the erosion of soil. Indeed, it is practically impossible to separate the effect of floods and of erosion. The erosion caused by floods may entirely destroy a forest by carrying away the soil in which the trees anchor their roots and from which their supply of food is obtained.

Another type of flood injury occurs on low-lying level lands where flood water ultimately collects and stands for appreciable periods of time at depths covering the root systems of trees. Where the trees are permanently flooded they are finally killed (Green 1947).

Swamp lands, as the name implies, are areas which have poor facilities for shedding water and which consequently have an excess of water either permanently or throughout an important part of the year. Floods add to the amount of water standing in swamps and thereby increase the damage suffered by swamp forests. Swamp forests are hindered in growth oftentimes to such an extent that only a stunted forest can be grown. The trees are relatively unhealthy and are constantly exposed to danger from windthrow, owing to the wetness of the soil and the shallowness of the soil layer in which they can develop

a root system. Tree roots are most abundant in the zone of soil lying above the level at which water stands during the growing season.

Erosion

Erosion is a natural process which has been in operation throughout the past and will continue to operate in the future. The wearing down of land masses by the action of water cannot be prevented. Erosion may be either normal or abnormal. Normal erosion is a gradual wearing away of land surfaces, which, although continually in progress, does not seriously affect the use of the land and its productive value until the vegetative cover is broken. Abnormal erosion is an accelerated type which erodes the land surface so fast as to destroy the productive capacity of the soil. It may occur either in the form of sheet or gully erosion. In sheet erosion, thin layers of the top soil are washed away, this process being repeated with each storm until eventually all the fertile soil is removed and the unproductive subsoil is exposed. Sheet erosion, because the general contour of the surface remains unchanged, is frequently overlooked until the land is well on its way to destruction.

Gully erosion, more spectacular than sheet erosion, cuts gullies into the land surface and is evident as soon as it starts. Once under way this type of erosion eats into the land with startling rapidity.

Erosion not only injures the land from which the material is removed but also may destroy the value of lower-lying lands by depositing upon them the eroded material. Such deposits are harmful when the material is of coarse texture and sterile nature, but when silt and other fertile soil material is laid down the lands covered may be benefited, as in many river bottoms. However, the occasional beneficial effects of erosion are more than counterbalanced by the injury to the lands from which the eroded material came.

Erosion varies greatly in character in different parts of the country. The geological formation, particularly the gradient of the land uplift, is a factor influencing erosion. Precipitation itself is a primary factor since water, along with gravity, furnishes the motive power for moving the soil. Severe erosion may occur in relatively level regions which have heavy precipitation and easily eroded soils.

Soil formation and texture are important factors in determining the extent and amount of erosion. Heavy clays are resistant to erosion, owing to the strong cohesion between soil particles. Coarse sands and

gravel are relatively resistant because of the speed with which water percolates through such material. The soils most susceptible to erosion stand midway between these extremes and are of a loamy or silty type. These are generally the most fertile soils.

Abnormal erosion cannot start in a properly managed forest. It may start in an altitudinal zone above the forest, or in exposed spots within the forest zone such as openings bare of vegetation and road cuts, or it may start below the forest and work back into it. Although erosion does not start in the well-managed forest, yet there are many ways in which it may start in the forest provided the management is not perfect. Such factors as fire, lumbering, the grazing of livestock, poisonous gases which kill vegetation, agricultural use, rights-of-way for highways, railroad, and other transportation lines, all furnish opportunities for erosion starting within or close to the forest. From these starting points, injury to adjoining pieces of well-managed forest may result. It is erosion accelerated beyond the normal rate by such artificial factors as those just named which is responsible for the serious phases of the erosion problem.

Landslides

Landslides are a special form of erosion. They are mass movements of soil sliding as a unit rather than the movement of soil as individual particles in a stream or sheet of water. Landslides are caused by masses of soil becoming filled with water or water-logged. If such portions of soil are located on level land, the excess water simply turns the area into a swamp and no landslide results. Where the soil on slopes becomes filled with water, the entire saturated body of soil may slip down to a lower level. Landslides are particularly likely to occur where some stratum either of impermeable soil or rock lies parallel to the slope and prevents the deeper entrance of water into the ground. It is easy for the soil above such a stratum to slide downward when it becomes saturated with water. Not only the soil but the forest along with it is carried down, leaving a bare exposed slope.

The forest in the path of a landslide is destroyed. Either the trees slide with the mass of soil or if the roots are anchored in firmer unsaturated strata the landslide passes through and over the forest, smashing the trees and burying the ground under deposits of rock, soil, and debris.

Injury from landslides may be expected in mountainous regions hav-

ing abundant rainfall. The area affected by a landslide ordinarily is a long narrow strip running from the top to the bottom of a steep slope.

Frozen Water: Snow, Ice, or Sleet

In cold climates a portion of the precipitation comes in the form of frozen water, or freezes after it reaches the trees or ground. Under certain circumstances this frozen precipitation may cause serious damage to the forest, through crushing, bending, or breakage of the trees. The injury results primarily from the weight of the frozen precipitation upon the trees and their movement by the wind when rendered stiff and brittle by the ice.

Snow has a beneficial influence in that it covers the ground like a blanket and prevents deep freezing of the soil as well as the heaving of small plants which often occurs on exposed soil. The snow blanket also assists in lessening injury to reproduction at the time of logging. Since the blanket of snow retards or prevents freezing of the soil, it facilitates the percolation of water into the soil. Indeed, as the snow melts on top of the ground, the snow-water may enter the unfrozen soil. On the whole, the beneficial influence of snow outweighs the damage caused.

Snow is particularly injurious under circumstances which cause it to fall in a moist, sticky condition so that it is caught in a large proportion upon the trees. A snowstorm of dry, finely divided particles sifts down through the trees and little is retained on them. The greatest likelihood that a large part of the snowfall will be held on the trees is found in dense stands of conifers where all the crowns are approximately the same height and the branches interlace strongly. Under such circumstances a fall of snow on a calm day may be retained almost in its entirety upon this flat crown of foliage. Should the snow be somewhat wet as it first falls and the temperature drop enough so that the light cover of snow on the tree tops freezes to the branches and foliage, then an exceptionally strong support may be created to hold up the succeeding snowfall. Thus a heavy sheet of wet, partly frozen snow may be laid upon the trees.

The usual damage which results from snow, ice, and sleet is classified either as snowbreak or snow-crushing. In snowbreak the stems of single trees are snapped off and branches are broken. Such injury occurs principally with ice and sleet.

In climates where winter rainstorms turn into hail and sleet, and

freeze on the tree, all parts of the foliage, branches, and trunk may become coated with a film of ice. After such a glaze storm, if the weather is calm, the coating of ice may melt and serious breakage be avoided. Should the storm be accompanied or followed by a strong wind before melting can take place, disastrous breakage of the heavily weighted and rigid, frozen branches and tree trunks results.

On the whole, climatic conditions in the eastern United States from the southern Appalachians northward lead to greater injuries from this source than elsewhere in the United States. Abell (1934) describes this type of injury in the southern Appalachians and states that it may be expected to occur periodically. Similar damage occurs in other parts of the country, and conifer types are often injured. McCulloch (1943) reports the results of an ice storm in second growth Douglas-fir. The wounds caused by breakage afford opportunity for the entrance of fungi (Campbell 1937). A minor form of ice injury is that caused by hail which mechanically wounds tender twigs and makes holes in the foliage. Lutz (1936) calls attention to another minor type of glaze injury. The ice coating frozen on small stems may cause horizontal lesions in the bark when the stiffened stem is bent by the wind, causing cracks in the ice coating and in the bark underneath. No serious consequences have been noted.

Snow-crushing is caused primarily by the weight of the snow and is exhibited in the bending of single trees, sometimes down to the ground, and in the distortion of their crowns in slighter injuries. Trees that have been bent by snow but continue to grow develop crooks in the main stem which may ruin them for lumber because of the crook itself and because compression wood is developed. Under the most severe conditions entire groups in the stand may be bent out of an upright position and sometimes crushed to the ground by the weight of snow. The bending of the stems is likely to result in loosening or breaking some of the roots.

Severe snow-crushing occurs most frequently in young stands. Dense stands of tall, slender saplings are fully as susceptible to snow injury as patches of reproduction. Snowbreak is most common with species having weak branches. Conifers suffer more from snow-crushing and snowbreak than hardwoods do, because their foliage is present during the snow season and there is consequently more surface upon which the snow may stick.

As information in a forest region builds up with the passage of time, it probably will be found that there are certain spots or zones where

climatic conditions are favorable for creating the special conditions likely to lead to extensive snow and ice injury. Other parts of the same forest may be almost exempt from it. Calm weather when the snow is falling is an essential for serious snow-crushing, since, when the wind blows, the falling snow, even though wet, is carried in larger part through the trees to the ground.

Since wind is a factor in preventing overloads of snow on the trees, it follows that the sites most protected from wind are likely to be those that suffer most from snow. Damage from snow-crushing does not necessarily develop immediately after the snowfall. In fact, the snow may lie on the trees for some time before the injury takes place. Ultimately the dead weight itself or the increase of this weight, by more snow or added water content or movement of the trees by wind, results in crushing the trees. The distribution of the weight on the tree also is of importance. If the tree is symmetrical and the load of snow well distributed, loss may not be suffered, whereas an unsymmetrical tree or one loaded too heavily on one side may be bent by the same weight of snow.

Curtis (1936) working in conifer plantations found that injury from snow affected trees with one-sided crowns more seriously than those of symmetrical form. Arrangement in small age groups is particularly hazardous when snow damage is expected, since the larger trees in the older age groups may shed their load of snow down upon the groups of younger trees, crushing them. A sparsely stocked stand of symmetrical trees appears to be the safest from snow-crushing.

Avalanches. An avalanche is the mass movement of a body of snow motivated by gravity. When large bodies of snow are involved and the distance traveled by the avalanche is considerable, as down a long slope, serious injury is done to obstacles like a forest stand which may be located in its path.

Avalanches when once started may break down and thus destroy the forest through which they pass. They do not start within the properly managed forest but originate above timberline and on cutover or burned areas.

Injury from avalanches is a possibility over only a small fraction of the forest area which is so situated, on steep mountain slopes, in regions of heavy snowfall and usually adjacent to timberline, as to be threatened by sliding masses of snow from the open lands at higher elevations.

Injury by Floods, Erosion, Landslides, and Avalanches to Lands Outside the Forest

It has already been stated that the forest may be seriously injured and portions even be destroyed by any of these agencies. Hence the forest should be protected against them as far as practicable. On the other hand, the forest itself has an important part to play in furnishing protection against these agencies to lands and property lying without the forest boundaries, sometimes adjacent thereto and sometimes far distant.

The worst effects of floods, erosion, landslides, and avalanches are felt outside the forest, either at elevations below the forest zone or on lands which were at one time forested but are now cleared. The agricultural lands and those used for other purposes outside the forest presumably are of greater value than the forest lands. Consequently protection against the effects of water to these lands may be more important than the protection of the forest itself.

The control of floods, erosion, landslides, and avalanches on agricultural, grazing, and other types of open land outside the forest is a conservation problem of primary importance but strictly speaking is only indirectly a forest protection problem. Although the forest cannot furnish complete protection from the effects of water to lands outside, yet when properly managed it becomes a most influential agency for this purpose. Adequate forest cover on the headwaters, upper slopes, and at critical points on the land of more gentle topography will appreciably lessen the injury which may be caused to areas outside the forest through excessive concentration and movement of water. The two important factors responsible for floods and soil movement are abnormally high precipitation and *unsatisfactory condition of the land area upon which this precipitation falls.* The extent and duration of the precipitation cannot be changed, but it is possible to maintain such a good forest cover that the effects, on lands outside the forest, of floods, erosion, landslides, and avalanches are minimized.

Lands ruined for agricultural purposes by these natural phenomena can best be made productive again by establishing a forest cover. Hence the forester will often be called upon to reforest lands badly eroded or covered with infertile deposits of rock and soil.

The large subject, covering methods of reclaiming and reforesting areas of this kind, belongs partly under artificial reforestation and partly under forest protection. It is, in the first place, essentially a

technique of reestablishing a forest on lands originally forested. The work is made difficult because of the deteriorated condition of the soil under past abuses and because of the possible continuing action of water and soil movement during the early stages of the reforestation program.

As soon as the plantation is set out, its preservation lies within the field of forest protection and usually presents a difficult problem for the forester. Indeed, it is on the lands already injured by the abnormal movement of water and soil that the greatest need for protecting the forest against floods, erosion, landslides, and avalanches exists.

Methods of Controlling Damage from Water in Excess

In considering methods of control, it must be recognized that occasional violent downpours, either cloudbursts or long periods of heavy rain, are to be expected, and the problem in control is how to take care of this excess precipitation without injury to the forest or to lands outside the forest.

Floods. The most effective method of controlling floods is by the use of engineering works designed for storage of as large volumes of water as there is reason to believe may be accumulated in single floods. The building of such storage reservoirs is justified only for the control of floods outside the forest. An exception to this statement does occur in mountainous regions where engineering works of a simple and inexpensive type above the forest zone may be justified in order to maintain the protective value of the forest.

The expense of storage reservoirs is very high, and in some parts of the country the topography is such that adequate reservoirs cannot be provided. Even where adequate storage is developed, the fact remains that the forest will be needed for protection to the reservoirs against their being rapidly filled with silt, as well as for direct protection to the lands outside the forest. Ashe (1926) has shown that where the life of a reservoir can be prolonged by reforesting the watershed, thereby preventing or lessening the deposits of silt in the reservoir, this should be done.

The forest must be kept in the best condition to absorb water. This means that the forest floor should be as sponge-like as possible, not compacted, or swept bare of its undergrowth by fire or grazing. This will insure the largest possible amount of water absorption and water percolation into the soil and at the same time will guarantee that what

surface runoff does occur, because of excessive amounts of water falling in a short time, will not cause erosion (Meginnis 1932).

To be of the greatest service in preventing floods, a forest must have plentiful forest litter and ground cover. The prevention of forest fires and either elimination or close regulation of grazing within forests and on open lands above the forest are essential for the maintenance of a forest litter and ground cover adequate to guarantee satisfactory absorption of precipitation (Bailey, Forsling, and Becraft 1934) and prevention of rapid surface runoff.

On nonforested slopes, even though protected from fire and grazing, in regions where the danger from floods is great, it may be necessary in order to prevent rapid surface runoff and erosion to build terrace-like trenches and check dams to hold the water long enough for it to sink into the soil (Bailey 1935).

Where the surface runoff carries off soil, quantities of silt are brought down into the storage reservoirs and may fill them within a relatively short space of time. Even where the water is stored in underground reservoirs, namely, deep deposits of gravel and rock strata, as in Southern California, the presence of silt in the water is likely to seal the top layers of these storage gravels and prevent adequate percolation of water into the underground storage basins (Cecil 1932). Keeping the water clear of silt is a stronger argument for retaining a forest cover on the watersheds of storage reservoirs than the argument that immediate surface runoff is lessened, although ordinarily this also results (Morris 1935).

On forest lands periodically subject to floods, species capable of withstanding inundation should be grown. Pollarding which keeps the young shoots above the floods is a suitable method of treatment. The selection and coppice with standards systems, under both of which methods a part of the stand always remains on the area, are better suited than other reproduction methods for application on lands subject to floods.

Drainage, where it is practicable, will lessen damage from excessive water in swamps. Although this action will benefit the forest in the swamp, the territory downstream may be injured as a result. Natural swamps often make good storage reservoirs, and indeed the region which has a fairly high percentage of swampland may be immune from dangerous floods. Draining such swamps decreases the storage capacity of the area for flood waters and tends to increase the height of floods lower down the valley.

Erosion. Erosion is best controlled by never allowing conditions favorable for its start to develop. Once started on a large scale, erosion is difficult and expensive to check, particularly on open lands. To reclaim badly eroded lands, the reestablishment of a forest cover ordinarily is required. This may have to be obtained artificially. In the worst instances, as on the watersheds of the so-called "torrents" in the European Alps, engineering works such as dams and stone walls must first be employed to check the movement of the soil before reforestation can be attempted. In many instances in this country badly eroded, mismanaged agricultural lands must be afforested. If agricultural lands cannot by correct management be prevented from eroding they should be turned back permanently to forest land.

The object is to prevent abnormal or accelerated erosion. The slow degradation of the land mass as a natural process will continue, but accelerated sheet erosion and all gully erosion should be prevented. The control of erosion is essentially similar to flood control as both hinge upon preventing rapid surface runoff. To accomplish this, the natural sod or herbaceous cover in the zone above the forest should be kept in good condition to absorb water and to prevent the erosion of soil when surface runoff does occur. Erosion above the forest must be controlled by conservative use of the land, particularly the prevention of fires and avoidance of overgrazing, supplemented by simple engineering works.

The engineering works appropriate in the zone above the forest are check dams across streamways and incipient gullies, and narrow terraces or trenches in which water may be held until it can be absorbed into the soil.

In the forest itself the most effective control measure against erosion is to maintain a fully stocked forest with an adequate forest floor. This is done by preventing the occurrence of forest fires, eliminating grazing, and on critical sites avoiding heavy cuttings of timber that might be likely to tear up the forest floor and scar the ground, thereby encouraging the start of erosion.

Proper maintenance of roads and trails is helpful. Roads must be carefully laid out to shed water without erosion and be provided with appropriate facilities such as culverts and ditches, paved when necessary, to carry off the water. Cuts and fills are particularly likely to erode and must be kept in condition by sodding, by planting trees or other plants, by using correct angles of slope, and sometimes by cribwork or retaining walls.

Kraebel (1936) shows that the relatively straight, low-grade roads

with wide curvature needed for modern fast automobile travel are out of place in mountainous regions subject to erosion, because such roads, on account of their immense cuts and fills, afford opportunities for the start of serious erosion. Mountain roads should be built with a minimum amount of cut and fill, with the use of retaining walls, cribbing, bridges, and tunnels if necessary, and with careful attention to drainage.

Below the forest zone or on open lands originally forested, the control of erosion is a separate problem in itself. Bare lands where erosion is starting or has already occurred can best be reclaimed by establishing a new forest. Sometimes immediate planting with suitable tree species will be successful, but frequently on seriously eroded areas some preliminary treatment is necessary before planting can be done. Trees, vines, creeping plants, and grasses may be used in planting eroded lands. Trees furnish the best permanent protection, but they cannot always be made to survive until other plants have become established and have stopped the most rapid erosion. The forest, because of its height and density, is a better protective soil cover than herbaceous plants or shrubs. The forest makes a heavier litter on the soil and over long periods of time is a better up-builder of the soil than the lesser vegetation.

Where gully erosion is actively in progress, preparation of the gully before planting will ordinarily be necessary. The heads of actively eroding gullies are the critical points which should be planted first before more land is invaded and ruined by the gully. As described by Meginnis (1933) it is advisable to plow in the upper edges of the gully and catch the fertile topsoil, so distributed, on the slopes or behind wire or brush dams built across the gully. In this way the bad soil conditions of the eroded land are quickly improved and survival of the trees is made possible. In some of the worst gullies or on uplands deeply eroded to the subsoil, where a cover of top soil is not easily provided, it may be necessary to dig holes in the eroded ground large enough for the trees and fill the holes with top soil. Straw, grass, or some similar material should be used back of the dams to filter out and hold the silt. Dams should also slope from the ends of the dam toward the center of the gully to prevent water cutting around the ends of the dam.

In the southern United States, 1-year-old seedling stock of black locust has been used largely in planting eroded lands. Shortleaf and loblolly pines, 1-year transplants, are also successful in the same region. Experience indicates that only the best grades of nursery stock should be employed for this difficult planting. The planting is relatively costly

and is justified not on the basis of the first forest crop that will be produced on the land itself, but rather because this planting will stop further erosion on the area planted and its extension upstream, and it will prevent injury from deposits of debris on lands further downstream.

Engineering works are expensive and should be used in erosion control only to the extent that they are indispensable to supplement the forest, or other plant cover where the forest cannot be grown, or temporarily while a vegetative cover is being established and developed to the point where it will itself prevent erosion.

The simple engineering works common in erosion control may be classed as:

1. Check dams of various types intended to check the velocity of the flowing water. They include brush dams, wire screen dams, wooden dams of logs or planks, crib dams, and loose rock, masonry, and concrete dams. Brush dams may last only 2 to 5 years and are intended to improve the site for the start of vegetation (Meginnis 1938).

2. Paving of various types. The principle is to place and maintain a layer of not easily eroded material over critical areas subject to erosion. It is used mostly in streamways and gullies between check dams, or in gullies where there are no check dams. The paving may be made either of brush, staked and wired down, or of loose rock tamped down into the soil or into a grout base. Mulch of straw or grass, placed under the brush, or loose rock pavement may be needed to stop erosion effectively.

3. Diversion ditches. These are often needed to turn water out of eroding gullies which are being reclaimed. These may also be necessary to afford a permanent outlet for water caught on terraces.

4. Terraces with retaining walls. On steep slopes above the forest zone it may be necessary to create terraces to check the velocity of the surface runoff and give time for the water to sink in. Stone retaining walls are sometimes needed to maintain these terraces.

The best methods of constructing these engineering works vary, depending upon the soil, topography, and climatic conditions encountered and the materials available for construction. Details of construction should be worked out locally.

Landslides. Landslides, as previously stated, are examples of a special type of wholesale erosion. Control measures are needed both above the forest zone and within the forest. Above the forest zone, engineering works like those to prevent other types of erosion should

be built on all slopes in danger of sliding. Grazing should be prohibited, and complete fire protection should be secured.

Inside the forest zone wherever danger from landslides exists complete fire prevention and elimination of grazing should be the rule. The clearcutting of timber should be avoided, and partial cuttings of the selection type, which always retain a large proportion of the stand, should be employed. It will often be necessary not only to maintain a good soil cover but also to anchor sheets of soil so that they cannot move. This may be done on loose banks by driving in a series of stakes, preferably of live wood which may sprout, and sometimes connecting these stakes with wire. The tree roots form the best insurance for holding large layers of soil once the forest is established.

Snow, Ice or Sleet, and Avalanches. Control of snow, ice, and sleet damage can be secured only through making the individual trees strong and providing room for the snow to fall through to the ground. When snow-damage zones are located, species not easily broken or crushed by snow should be favored and an arrangement of age classes planned which will prevent the dumping of snow on young age groups. Dense, even stocking must be avoided as well as mixtures of species ill suited to resist snow damage. For example, a mixture in which one species outgrows the other usually results in the slow-growing species forming slim stems with unsymmetrically formed crowns which are broken or crushed by the snow dropped upon them by the faster-growing species. An ideal mixture for protection against snow is composed of a conifer and a hardwood, the conifer preferably being the faster growing of the two. The conifer sheds its snow upon the hardwood, which species, being without foliage in the winter, allows the snow to fall through to the ground.

Skillful thinning is the forester's chief tool for developing strong individuals capable of resisting snow damage. Trees with one-sided crowns should be eliminated from the stand in the thinnings unless they are needed in the dominant stand.

Curtis (1936) suggests that trees with one-sided crowns should be brought to symmetrical form by artificial pruning and thus be safeguarded against being bent over by the weight of an unequally distributed load of snow. He also advises that thinnings be made after the year's heavy snowfall is completed, so that the remaining trees may have the advantage of a season's growth in this new, more exposed position before being subjected to heavy snowfall.

Where snow damage is threatening, thinnings of the low thinning type rather than crown thinnings may be safer. The subordinate stand

maintained in the crown-thinning method is likely to be ruined by the snow sliding down from the trees in the upper canopy.

Damage caused by ice forming on the trees (glaze or sleet storms) cannot be prevented. The effects of such storms may be minimized eventually by encouraging the more resistant species. Downs (1938) found in northern hardwood stands that hemlock was lightly injured, while black cherry, basswood, and aspen were badly hurt. On the whole, conifers suffer less than hardwoods because they have smaller upper crowns and better branching habits to resist weight on crowns.

Gradual strengthening of trees by thinnings to develop sturdy stems and crowns should reduce the most serious types of damage. The maintenance of an even canopy without trees projecting far above the general level is desirable.

Avalanches, or the mass movement of snow on slopes, once started are difficult to stop; hence protective measures should be directed toward preventing their origin. Long grass, ground cover of any kind, brush, and reproduction hold the snow and assist in preventing the start of avalanches. Above timberline, protective measures include the encouragement of all woody-plant vegetation, the preservation of a grass sod, and at the most dangerous points the construction of ditches, walls, and fences.

Below timberline, protective measures require the maintenance of a protection forest. Munger (1911) mentions four requirements for treatment of such a forest.

1. Complete fire protection. This encourages the development of ground cover, underbrush, and reproduction.

2. Exclusion of grazing with the same object in view of keeping the soil densely covered.

3. Careful cutting of timber on steep slopes with a gradient exceeding 50 per cent. Single-tree selection is the proper method of reproduction. Clear cutting should be prohibited.

4. Prompt reforestation of denuded areas, in order to reestablish forest conditions.

Avalanches in this country occur most frequently in the Cascade Range in the Pacific Northwest, where two types are recognized, canyon slides and slope slides. Canyon slides start on steep slopes at the head of canyons usually above timberline and result from heavy snowfall on steep unforested land. Slope slides originate on steep cutover or burned-over mountain sides. A properly managed forest will control slope slides, but canyon slides can be controlled only by engineering works.

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CHAPTER 20

Protection against Atmospheric Agencies (Continued)

WIND

Wind affects the forest in a variety of ways but on the whole is injurious. These effects of wind may for our purpose be classified under the following headings:

Effects upon the soil.
Effects upon the forest atmosphere.
Direct physiological injury to trees.
Mechanical injuries.

The beneficial influence of wind is found primarily in the dissemination of seed and pollen (Forbes 1925). Natural regeneration relies largely upon wind-borne seed for stocking cutover areas. Another beneficial influence of wind is the mixing of the soil which occurs as a result of large trees being uprooted. Oftentimes the forest litter is buried and mineral soil exposed, which may afford a favorable seedbed for species not then abundant in the stand. Over a long period of time in the virgin forest an appreciable portion of the forest floor may be disturbed in this way (Lutz and Griswold 1939). This action is of more significance in affecting soil conditions and the composition of forests in their natural state than in the managed forest.

Effects upon the Soil

The wind exerts a distinctly injurious influence upon the soil in two ways: first, by blowing it away, which is commonly spoken of as wind erosion; and, second, by its drying effect upon the soil in place. Accelerated air movements increase the evaporation and tend to exhaust

soil moisture. The continued drying action of the wind upon the soil interferes with the building up of the better types of humus, is likely to develop instead a tough, peaty acid humus layer, and also curtails the activity of the soil bacteria and fauna necessary for proper functioning of the soil (Fritzsche 1933). Oftentimes the entire cover of leaves is blown off, leaving the soil bare, and conversely in other spots these leaves are heaped up thickly, with bad results both for regeneration and for condition of the soil.

Wind erosion, the other type of wind action on the soil, results in the movement of the soil particles themselves and their removal from their existing position. Fine earth is continually being blown away from exposed portions of the soil in the forest. This occurs especially on the warmer, drier exposures such as southern-facing slopes. In the long run this removal by the wind of fine particles of soil results in making the soil shallower and less fertile. Since the fertility of the soil determines the productive power of that area for tree growth, any injury to the soil affects the growth rate of the forest unfavorably.

Not only are fine earth particles constantly being removed from exposed spots in the forest, but a most striking type of action occurs where the wind blowing over areas outside the forest causes a wholesale movement of soil. This is usually discussed under the head of shifting sand dunes, although similar wind action takes place also on areas of finer and better soil types.

In general, wind erosion increases as the percentage of sand in the soil rises and is most dangerous in regions where extensive bodies of fine, dry sand occur. Moving sand dunes are capable of burying and destroying entire forests, and conversely the establishment and maintenance of forests upon areas of shifting sands constitute the only method of rendering such areas productive and preventing injury to adjacent property including forests.

Wholesale erosion of soil by wind may start even within a forest where mismanagement has destroyed the litter covering the soil. Wind erosion is a potential source of danger to the forest, principally in regions of light sandy soils where the precipitation is relatively scanty during at least part of the year. Soil materials cast up by the sea and not yet clothed with vegetation are particularly susceptible to wind erosion and threaten adjacent forests and property.

Mismanaged agricultural lands suffer enormous losses of soil from wind erosion each year, but consideration of this problem, except as the wind-blown soil threatens to overwhelm forests in their paths, is outside the scope of the discussion.

Effects upon the Forest Atmosphere

For perfect functioning of the forest community the air within the forest should be calm, moist, and relatively warm. When these conditions prevail excessive evaporation and transpiration are avoided and the humid atmosphere enables the trees to elaborate food materials to greatest advantage. Particularly is the supply of carbon dioxide, so necessary for plant activity, abundantly available. Where wind is admitted into the inner part of the forest this favorable condition is changed. The carbon dioxide is rapidly carried away, and the forest atmosphere may be cooled by the influx of colder air. Thus, the warmth secured from the sun's rays and held within the forest may be lost. Or the wind may be excessively hot and dry and then it will raise temperatures too high and decrease the moisture within the forest. From whatever angle the subject is approached, it remains a fact that the free movement of wind inside the forest affects the forest atmosphere unfavorably and should be prevented.

Direct Physiological Injury to Trees

The physiological effect of the wind is expressed in a variety of ways. It deforms the crown, changes the nature of the root system, and stunts the height of the stand. Trees along the border of a stand exposed for long periods to strong winds coming from one direction have deformed crowns and have root systems especially developed to hold fast against these winds. The strongest will be developed on the leeward side of the tree to furnish resistance to bending (Fritzsche 1933). The height of the trees will be less on the outer exposed edge, and normal heights will be attained only 60 to 200 feet inside the border (Münch 1923).

Wind action sometimes causes excessive development of the root system at the expense of the growth of the portion above ground.

Wind often is responsible for the drying out of tops of trees, creating what is known as a stagheaded condition. In fact, much of the injury to trees left isolated on cutover areas and attributed to changed site condition is caused by wind action in drying out the soil and increasing the loss of water from the tree. From the physiological standpoint the wind question is in many instances a water-supply question.

Wind-blown salt water even if diluted by heavy precipitation may damage foliage and buds and even woody stems in semi-dormant condition. Moss (1940) describes the effect along the Connecticut coast of

wind-driven salt water after the New England hurricane of 1938. With wind velocities in excess of 100 miles per hour damage was found 45 miles inland. The foliage of conifers was killed and browned as if by a forest fire, although the color was more a reddish-orange. The hardwood foliage was stripped off by the force of the wind, but buds were killed by the salt spray.

The most important injurious physiological effect comes from an increase in the transpiration from leaves and twigs. It is sometimes claimed that growth may be stimulated by a reasonable increase in transpiration and that light winds may even be of benefit in this respect. However, strong winds soon raise the rate of transpiration beyond the point most favorable for tree growth. This, combined with the water shortage for the roots, which may be brought about by heightened evaporation from the soil, has serious consequences for the growth and health of the forest. The wind often turns the leaves into positions unfavorable for assimilation. They may also be cooled by the wind, and this results in interference with normal nutrition. Wind movement may cause the closing of the leaf stomata and thereby hinder entrance of carbon dioxide into the leaves. All in all, the wind is of distinct physiological importance in deforming the trees and in reducing the growth of the stand (Barth 1934).

These physiological influences of the wind are in progress even with winds of low velocity, but mechanical injuries, often spectacular in nature, occur principally in the occasional windstorms of high velocity. Consequently, it is possible that the physiological injury suffered by the forest from wind may be greater than that resulting from breakage and windthrow. In fact, there are places, usually located near the border line between the forest and other types of vegetation, where wind is a sufficiently critical and a powerful enough factor to destroy the forest and replace it permanently with other vegetation unless conservative management is practiced directed especially toward minimizing the influence of wind, particularly in its relation to transpiration.

Mechanical Injuries

Strong winds have the power to tear out entire trees by the roots, to overthrow whole stands, and to snap in two the trunks of large trees. Where occurring in the most violent form, as in the tornadoes and hurricanes of the southern United States and tropical countries, the wind cuts a wide swath through the forest, knocking down and

breaking all the trees in its path. Complete destruction of the forest may result from such violent storms.

What may be termed the normal storm, examples of which occur at frequent intervals in all forest regions, is a constant source of windthrow and wind breakage in the forest.

Winds of lesser intensity, which do not cause overthrow or breakage, lash the small branches against one another, thereby knocking off an appreciable amount of the foliage and small twigs. Tearing and loosening of the roots are frequent wind injuries. Such injury which is often hard to observe above ground may cause a shortage of water supply for the tree, because the fine roots are broken, thereby lowering the vitality and increasing the susceptibility of the tree to injury by insects and fungi. Trees of all ages are uprooted and broken by high winds, but, on the whole, old timber suffers most. The velocity of the wind is the main factor governing the extent of damage. Low-velocity winds cause practically no mechanical damage. Until velocities in excess of 30 miles per hour are reached, little mechanical damage is caused by wind. High winds accompanied by rain or wet snow cause the worst injury.

Windfall is most likely to occur in seasons when the soil is saturated with water and consequently the holding power of the roots is least effective. Under such conditions species relatively wind-resistant may be uprooted. Soil texture also influences windfall since it affects the distribution of the roots. On sandy soils there is practically no windfall unless the soil is shallow and underlaid with an impervious stratum. On heavy fine-textured soils windfall is more common. Shallow-rooted species suffer most, and conifers are more susceptible to wind damage than broad-leaved trees particularly when the leaves are off.

Schantz-Hansen (1937) describes damage done by a 60-mile-per-hour gale following a rain in northern Minnesota. The windthrow on upland areas was slight, but in an all-aged spruce and balsam swamp, uncut, nearly one-third of the spruce and balsam were windthrown. Where an improvement cutting had been made very little loss occurred.

Jensen (1941) found, after the New England hurricane of 1938, that heavier losses occurred in unevenaged stands than in those of evenaged form. He attributes this result to differences in the crown-canopy arrangement in the two forms of stand. The more uniform canopy of the evenaged stands exposed the individual trees less to the wind than the irregular canopy characteristic of unevenaged stands.

In a study made after the New England hurricane of 1938 Curtis

(1943) showed that, even in this storm of exceptional violence, certain types of trees were more resistant to wind than others. The resistance to windthrow depended on the type of crown and height of the form point.* In general, trees with a low form point withstood the wind better than trees with a high form point. Trees with deep crowns, those with storied open crowns, through which the wind could blow were found to be relatively wind-resistant. An apparent exception occurred in the case of tall, slender intermediate trees with small crowns, 10 to 20 per cent of the total height, which were supple enough to absorb some of the wind pressure without being injured.

A peculiar type of mechanical injury by wind has been reported by Moore (1933) and Day (1934). This consisted in the girdling of recently planted Scotch and Corsican pines by the action of wind swaying the stems against sharp stones lying in the surface soil.

The action of wind is felt in every forest in the country. The amount of damage varies tremendously from place to place. In general, regions of relatively low precipitation and high average wind velocity suffer the greatest injury. Forest regions subject to violent wind storms of high velocity show the greatest damage from mechanical breakage and overthrow of timber.

Trees growing in isolated position from early youth develop a proper balance between roots and top, develop sturdy anchoring roots, and accustom themselves to resist the winds normal to their locality. They are in the best position to weather the occasional violent storms safely. The roots which strengthen trees against windthrow are not the long feeding roots but the larger shorter roots of the bracket angle type developed particularly on the leeward side of trees in exposed situations. These thick roots with the mass of interlacing roots between them were named by Fritzsche (1933) the "rootball." The rootball gives the tree its support against the wind. Trees grown from early youth in closed stands have the least resistance to the winds of normal intensity and may suffer complete destruction when their position in reference to adjacent trees is changed by cutting or when the occasional violent storm occurs.

Jacobs (1936) has called attention to another type of wind injury which he considers more harmful in the broadest sense than windthrow and breakage. This is the creation of uneven density in wood structure or the formation of compression wood, making the timber pro-

* Form point is the distance from the ground to a point one-third of the distance from the base of the crown to the top of the tree expressed as a percentage of the total height.

duced of relatively low quality. The wind sometimes creates permanent bends in the trees, which may all be leaning in the same direction. In leaning trees compression wood is produced, seriously injuring the quality of timber.

Methods of Protection against Wind

Complete prevention of injury from wind is impossible, but the damage during the life of a forest crop can be lessened by correct methods of management. The best protection against injury from wind is to prevent the entrance of the wind into the forest. This can be accomplished in theory by keeping the edges of stands where they abut on open lands completely clothed with dense foliage from the tops to the ground and by maintaining all through the forest a dense understory which reaches from the ground to the bottom of the dominant crown level. Such a condition is almost impossible to secure and maintain.

An unevenaged forest with the ages arranged by single trees or very small groups also constitutes a wind-resistant forest. The unevenaged forest is less susceptible to wind injuries of a physiological nature than the evenaged forest. For this reason the unevenaged forest should be developed and maintained on areas where severe injury of a physiological nature from wind is anticipated. The unevenaged forest because of its complete vertical closure reduces wind movement and evaporation inside the stand to the minimum. Sometimes, however, entire abandonment of the evenaged form of forest may be undesirable. Possibly adequate protection may be secured by maintaining a relatively narrow border of forest in unevenaged form while the main central area remains evenaged.

In second growth forests, under intensive management, unevenaged and evenaged forests show little difference in susceptibility to mechanical injuries by wind. In fact, evenaged stands properly arranged may suffer less injury than unevenaged.

Very rarely can such full protection against wind be obtained or justified when considered in relation to management objectives. If the forest products are to be utilized, cuttings must be made and the forest opened up, and wind will be admitted to a greater or less extent. The practical problem is to combine the production and utilization of timber crops with reasonable protection against wind, an ever-present enemy of the forest.

It should be remembered, however, that the degree of departure from

the ideal condition of the stand as regards exclusion of wind will be correlated with a gradual decrease in the growth rate of the stand and an increased liability to excessive mechanical injury from the wind. There are areas so dangerously exposed to injury from wind that on them a highly wind-resistant forest cover should be developed and maintained by light cuttings. Many other parts of the forest may be so slightly susceptible to damage by wind owing to favorable climate or other factors that special protection need receive relatively little consideration. This is true particularly as concerns damage from wind to soil, forest atmosphere, and physiologically to trees, and to less degree as regards breakage and overthrow of trees.

Injury from windfall and breakage, though occurring in stands of all ages, is of chief importance in mature timber. Such stands have attained their growth, are ready to harvest, and will be cut soon. Young and middle-aged stands, on the other hand, must be tended for many years before the time for harvest, and it is essential that they be protected against the entrance of wind with its serious consequences in reduced growth. Windfall and breakage are less common in these immature stands unless a tornado happens to pass through them.

Protection against loss to mature timber from windfall and breakage is needed virtually everywhere. In the utilization of the timber, cuttings must be made and when made are likely to leave exposed the sides of forest stands and to allow wind to blow against trees which previously have been sheltered by their neighbors.

Cuttings of any kind increase the wind damage and, in regions where this is serious, must be planned so as to minimize the extent of the injury. It is a fact that serious windfall and breakage occur in forests long under management, as well as in unmanaged forests. This is attributable partly to bad practices and failure to recognize wind as a sufficiently important potential source of injury and partly to the fact that, in the managed forest, cuttings of mature timber must be made each year, and hence numerous opportunities for windthrow and breakage exist on areas in the process of being reproduced.

Arrangement of the cutting areas so that they progress against the direction of damaging winds is accepted as one of the first principles of protection against mechanical injury from wind. In fact, if this arrangement is accomplished it is likely to be of greater protective value than a resistant border zone, since the entire forest is protected throughout. If successive cuttings are made on the leeward side of the stand and advance into the wind, the cut edges will not be exposed to direct impact of the wind. It will take more than a single timber-

growing rotation to accomplish such an arrangement of cutting areas.

The windward side of the stand should be developed as a border zone stocked with wind-resistant trees to act as a buffer for the remainder of the area. A long period of years is required to develop such a border, whether it be a single row of trees or a broad belt. Preferably a belt 50 to 100 feet wide should be developed in exposed situations. The trees in this zone must be developed gradually from early youth by repeated thinnings so that they possess exceptionally broad crowns and sturdy stems and are strongly rooted to withstand as individual trees the onslaught of the wind. A dense understory of other vegetation and the retention of branches down to the ground on the border trees will add to the wind-resistant value of the border zone.

Heavy thinnings particularly of the crown-thinning type started early and repeated often are of use as a wind-protective measure, not only in the border zone but throughout the entire forest area, and constitute one of the most effective means at the disposal of the forester for minimizing losses from windfall and breakage. Thinnings made primarily to develop wind-resistant trees will be heavier than is desirable for most other silvicultural purposes and will tend to develop relatively deep-crowned, symmetrical trees with stocky, fast-tapering stems. If thinnings are started early, trees can be made wind-resistant to all but storms of the tornado type on practically any situation no matter how exposed. The density of stand and the length of time during which the tree has grown under such conditions of close stocking, rather than the degree of exposure of the site, are the determining factors in its ability to resist mechanical injury from wind.

In managing stands on wind-swept areas some forms of clearcutting or of the strip type of reproduction are often the only methods of regeneration that are possible. This is especially true where the forest is made up of fully stocked, evenaged stands which have in the past been thinned lightly or not at all. Evenaged stands which have been thinned heavily and several times may be sufficiently resistant to admit of other reproduction methods than clearcutting.

The shelterwood method is likely to heighten the storm damage and is applicable only locally in the best-protected places and under intensive management. When intensively applied with frequent removal cuttings windthrown trees are soon salvaged without appreciable loss. The seed-tree method should not be employed with shallow-rooted species or on areas subject to windthrow. The selection system offers the best protection but is possible of application only if the stands are truly unevenaged or have been so managed from an early age as to

make the individual trees wind-firm; otherwise selection cuttings may expose the stand to great damage. Cutting in narrow clear-felled strips has advantages from the standpoint of protection against wind as well as other desirable features silviculturally and will often be practiced as forests come under management. Since old timber is more subject to windthrow than younger stands, shortening the rotation will have the effect of eliminating the serious losses of this type which occur today in areas of virgin timber.

Wholesale windfall and breakage in the path of violent storms and tornadoes can never be prevented in stands of any age, irrespective of composition or treatment.

Control of Wind Erosion. The problem of erosion by wind, like that of water erosion (page 302), has two phases: first, the protection of the forest against injury caused by erosion of soil, starting either on areas within the forest or on lands outside and moving into the forest; and, second, the reclamation of lands ruined by wind erosion. The former is a forest protection problem; the latter is in the field of artificial establishment of forests but becomes a forest protection problem as soon as the area is seeded or planted. Reclamation ordinarily involves the establishment of a vegetative cover, sometimes grasses and shrubs at first but in the final stage forest trees.

In guarding against the start of wind erosion within the forest itself the important principle is to preserve intact the humus, litter, and ground cover making up the forest floor. Where this is done the wind has no opportunity to blow away any of the soil. In forests where soil and climate are potentially favorable for the start of wind erosion any little exposure of the soil may be enough to encourage the start of wind erosion, and a blow hole once started is rapidly enlarged by the wind.

Exclusion of the wind from the forest by means of a dense wall of foliage down to the ground and by a thick understory will of course prove effective in preventing erosion without further attention. Wherever the forest has been opened by cuttings, it becomes important to preserve the forest floor intact if wind erosion threatens. In some regions grazing of domestic animals may be a cause leading to wind erosion. Animals should be excluded or closely regulated to prevent overgrazing. Forest fires should be prevented on all areas liable to injury from wind erosion.

Provided that the forest floor is unbroken and reproduction starts promptly on the cutover area, practically any system of cutting may be allowed as far as the danger of wind erosion is concerned. This is evident from experience in the maritime pine region of France, where

thousands of acres of sandy soils susceptible to wind erosion have been reclaimed and are managed under a clearcutting method.

Shifting sands, the movement of which originates outside the forest, may advance into and destroy a forest, even one kept in perfect condition to prevent the start of wind erosion. Once in motion, advancing sand dunes threaten to destroy any forest in their path and can be checked only by establishing and maintaining a vegetative cover upon the wind-blown soil. Hence for the protection of the forest itself those areas which adjoin it, where the wind is actively eroding the soil, must be reclaimed.

Eventually a forest should be developed and permanent control of further movement of sand be sought through maintenance of a thick forest floor. Any disturbance of the forest floor which exposes the mineral soil, such as the ruts in a forest road, forest fires, or grazing, may lead to movement of the soil and ultimate destruction of the forest.

Methods of stopping the movement of shifting sands form a special subject in itself to which full consideration cannot be given here. In general, planting must be undertaken. As a preliminary step, the movement of the sand must be stopped temporarily. This may be accomplished most cheaply by planting beach grass (Lehotsky 1941). A more expensive but effective method is to use cut brush, either paving the ground with it or constructing a close network of low fences dividing the area into small enclosures. Recent practice appears to indicate that, at least for sand dunes away from the sea, trees may be immediately established with the assistance of a dead-brush cover without the preliminary planting of grasses.

Kroodsma (1937) was successful in developing methods for stopping the movement of sand dunes in Michigan. He states that sand dunes in Michigan move forward at the rate of 1½ to 2 feet per year. His methods are summarized in the following paragraphs. An essential step is the spreading of a brush cover at right angles to the wind direction over the area on which the soil is to be fixed. This may be done before or just after the trees are planted. Hardwoods are usually planted first, and later conifers can be introduced in spaces left for the purpose. The hardwoods serve as a protective cover for the conifers until they become established.

The trees considered best for sand-dune planting are black locust and cottonwood among the hardwoods, and ponderosa, Scotch, Norway, and jack pines. Stock big enough so that it is not covered by blowing sand the first year should be used. This means about 18-inch 1-0

seedlings or cuttings for hardwoods and 2-1 or 3-0 stock for conifers.

After the planting is completed and the brush cover laid, the sowing of rye in the following fall is advised to furnish a winter mulch. This sowing may be repeated in several succeeding years if needed to prevent soil movement.

For reforesting Vermont sand dunes Altpeter (1941) recommends jack, pitch, red, and Scotch pines and black locust, each on the site to which it is best suited. He advises brush fences 4½ feet high with the brush woven between posts 2 feet apart or packed between two rows of post.

Mulch of a variety of materials is valuable not only for its mechanical control of sand movement but also because it lowers surface soil temperatures, thereby decreasing water losses through evaporation, and enables moisture to rise closer to the surface. The physical properties of the soil are changed favorably, and the mulch may contain extra nutrients.

SMOKE AND POISONOUS GASES

The smoke and poisonous gases cast into the atmosphere by industrial plants, railroad locomotives, and other sources pollute the atmosphere and injure forest vegetation. Smoke is variable in composition, but ordinarily in addition to the soot it contains other materials and is always accompanied by various gases. These gases frequently contain free acids and have a poisoning effect which may even kill the entire tree. Industrial plants where smelting of metals is carried on are the most dangerous as regards emission of smoke and gases. The most dangerous gases commonly present in smoke are those containing sulphur such as sulphur dioxide (SO_2). Sulphur dioxide in very small quantities is sufficient to kill vegetation. Illuminating gas also contains poisonous compounds but is of little importance as a source of injury to forest trees, although in towns and cities it is a common cause of the death of shade trees growing near gas mains. Another poisonous element is arsenic, which is often emitted in smelter fumes. Even though this arsenic, deposited externally, may not damage the timber, it may be deposited in sufficient quantity on forage to poison grazing animals.

Injury is caused to the forest in a variety of ways. The soot, dust, and other impurities settling from the smoke may form a coating over vegetation. Such deposits not only block up the stomata, thus impeding transpiration and absorption of carbon dioxide, but also, by cover-

ing the leaves, reduce the intensity of the sunlight as it affects the trees and thus interfere with photosynthesis (Bakke 1913). The deposits may contain substances directly injurious to the leaves through corroding or toxic action.

The effects of injury by smoke and its accompanying poisonous gases will usually be noted first through the discoloration of foliage, later by defoliation, and eventually by the death of injured portions or of the entire tree (Toumey 1921). Where the injury is not serious enough to kill the tree, there will at least be a decided slowing-up in the growth rate of forest trees subjected to continuous exposure to smoke and gases.

Fortunately most forest areas are not exposed constantly to large volumes of smoke with their poisonous fumes. It is only in the neighborhood of occasional smelters that the damage becomes extreme. The intensity of the attack depends primarily upon the concentration of the poisonous gas and the distance from the smokestack, modified, however, by wind direction and topography.

The worst injury is concentrated in the vicinity of smelters such as the one maintained by the Anaconda Copper Company at Anaconda, Montana. In the vicinity of plants of this type, forest vegetation unless located in areas sheltered from the smoke stream may be destroyed for miles around the plant. Mason (1915) states that destruction of lodgepole pine forests occurred in some places 9 miles distant from the Anaconda smelter and that slight damage was experienced at distances of 30 miles.

Conifers suffer more severely than broad-leaved trees, primarily because they retain their foliage for more than 1 year. The older foliage on the conifers, having been affected longer by the poisonous fumes, is likely to show more severe injury than foliage of the current year's growth.

Prevention of injury to forest trees from smoke and poisonous gases must come through treatment of the smoke before it leaves the stack. The matter of controlling the emission of poisonous gases and smoke from industrial plants has been investigated quite thoroughly, both by men in this country and by workers abroad, because of the injuries suffered by vegetation in cities and towns and because of the deleterious effect which smoke and its attendant fumes have upon human health.

It is now known that the pollution of the atmosphere by the emission of smoke and poisonous gases can be prevented, in entirely practicable ways, by scientific construction and skillful operation of the industrial plants. There is no longer any adequate excuse for the con-

tinuation of this type of injury to forest vegetation. The most serious cases of extensive injury to the forests in this country from smoke and poisonous gases occurred several decades ago. Today enlightened sentiment and improved practice, which recovers by-products from the poisonous elements in the smoke stream, should result in preventing further serious losses.

Different species of trees show differing degrees of susceptibility to injury from smoke and poisonous gases. In planting areas subject to smoke currents, species of known resistance to such types of injury should be chosen. As yet this information is available to only a limited extent. Mason (1915) arranged the Rocky Mountain species occurring in Montana in the following order of susceptibility, the first being the most susceptible: alpine fir, Douglas-fir, lodgepole pine, Engelmann spruce, western juniper and limber pine. Since complete elimination of the smoke and gas nuisance should be secured in the manner already described, there should be little if any occasion for restricting forest planting to species nonsusceptible to smoke and gas injury.

LIGHTNING

Lightning is a widespread source of injury to forest trees. Trees are excellent conductors for electrical discharges between the clouds and the earth and are frequently struck by lightning. Evidences of lightning injury, varying widely in character, can be seen in practically all parts of this country.

Lightning injures trees first by shattering the tree either in whole or in part, with a wide variation in the extent of the damage, and second by killing the tree without any splintering or mechanical injury.

Sometimes an entire tree is literally blown to pieces with splinters scattered in radii of a hundred or more feet. In other cases pieces of bark may be knocked off with minor injury to the tissues immediately beneath the bark. A common type of shattering is a furrow opened up in the bark and cambium layer often running nearly the entire length of the tree. Where such a groove follows a spiral grain the tree may be girdled.

When trees are killed without external evidence, the lightning apparently spreads over the entire trunk of the tree or kills the root system. Occasionally a small group of trees are killed by lightning without external sign, rendering it difficult to determine the cause of death.

It is believed that lightning strokes from clouds to ground shatter

trees, while discharges from earth to clouds often injure roots and sometimes kill trees without external evidence (Dodge 1936).

Damage to the forest from lightning is usually considered of minor importance as compared to other sources of injury. However, individual trees struck by lightning can be found scattered through the forest in most forest regions. Reynolds (1940) lists lightning as the chief cause of loss of volume through mortality in selectively cut stands of loblolly and shortleaf pines. In ponderosa pine stands in Arizona, Wadsworth (1943) reported that the trees struck by lightning amounted to about one-third of the total timber mortality.

There is no practical method of preventing lightning injury to forest trees. Lightning causes much more serious damage to the forest indirectly through starting forest fires than it does through direct injury in striking individual trees. Lightning is, in fact, one of the chief causes of forest fire in the United States. The consideration of lightning as a fire cause and of the control of fires originating from this cause belongs more properly under the head of forest fires and therefore has been discussed in Chapter 5 rather than in the present chapter.

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Appendix

Common and Scientific Names of Tree Species Mentioned in the Text

Common Name	Scientific Name
Ash, black	*Fraxinus nigra* Marsh.
Aspen, bigtooth	*Populus grandidentata* Michx.
Basswood, American	*Tilia glabra* Vent.
Beech, American	*Fagus grandifolia* Ehrh.
Birch, gray	*Betula populifolia* Marsh.
paper	*Betula papyrifera* Marsh.
yellow	*Betula lutea* Michx.
Cherry, black	*Prunus serotina* Ehrh.
Chestnut, American	*Castanea dentata* (Marsh.) Bork
Cottonwood	*Populus* sp.
Douglas-fir	*Pseudotsuga taxifolia* (Poir) Britt
Elm, American	*Ulmus americana* L.
Fir, alpine	*Abies lasiocarpa* (Hook.) Nutt.
balsam	*Abies balsamea* (L.) Mill.
white	*Abies concolor* (Gord.) Engelm.
Hemlock, eastern	*Tsuga canadensis* (L.) Carr.
Hickory	*Hicoria* sp.
Incense-cedar, California	*Libocedrus decurrens* Torr.
Juniper, western	*Juniperus occidentalis* Hook.
Larch, eastern	*Larix laricina* (Du Roi) K. Koch.
western	*Larix occidentalis* Nutt.
Locust, black	*Robinia pseudoacacia* L.
Maple, red	*Acer rubrum* L.
sugar	*Acer saccharum* Marsh.
Oak, black	*Quercus velutina* Lamarck
chestnut	*Quercus montana* Willd.
red	*Quercus borealis* Michx. and *Quercus borealis* maxima (Marsh.) Ashe
scarlet	*Quercus coccinea* Muench.
white	*Quercus alba* L.
Pine, chir	*Pinus longifolia* Roxb.
Corsican	*Pinus laricio* Poir.
eastern white	*Pinus strobus* L.
jack	*Pinus banksiana* Lamb.
limber	*Pinus flexilis* James

Common and Scientific Names of Tree Species Mentioned in the Text (*Continued*)

Common Name	Scientific Name
Pine, loblolly	*Pinus taeda* L.
lodgepole	*Pinus contorta latifolia* S. Watson
longleaf	*Pinus palustris* Mill.
pitch	*Pinus rigida* Mill.
ponderosa	*Pinus ponderosa* Dougl.
red (Norway)	*Pinus resinosa* Ait.
sand	*Pinus clausa* (Engelm.) Sarg.
Scotch	*Pinus sylvestris* L.
shortleaf	*Pinus echinata* Mill.
slash	*Pinus caribaea* Morelet
sugar	*Pinus lambertiana* Dougl.
western white	*Pinus monticola* Dougl.
Redcedar, eastern	*Juniperus virginiana* L.
Redwood	*Sequoia sempervirens* (Lamb.) Endl.
Spruce, black	*Picea mariana* (Mill.) B.S.P.
Engelmann	*Picea engelmannii* (Parry) Engelm.
Norway	*Picea excelsa* Link.
red	*Picea rubra* Link.
white	*Picea glauca* (Moench) Voss.
Sycamore, American	*Platanus occidentalis* L.
Willows	*Salix* sp.
White-cedar, northern	*Thuja occidentalis* L.
Yellowpoplar	*Liriodendron tulipifera* L.

Common and Scientific Names of Plant Diseases Mentioned in the Text

Common Name	Scientific Name
Blight, chestnut	*Endothia parasitica* (Murr.) A. & A.
Canker, larch	*Dasyscypha willkommii* (Hart.) Rehm.
Nectria	*Nectria* sp.
Strumella	*Strumella coryneoidea* Sacc. & Wint.
Tympanis	*Tympanis* sp.
Disease, brown spot needle	*Septoria acicola* (Thum.) Sacc.
mottled bark	*Stereum sanguinolentum* Alb. & Schw.
Mistletoes, dwarf	*Arceuthobium* sp.
true	*Phoradendron* sp.
Rot, Fomes root	*Fomes annosus* (Fr.) Cke.
shoestring root	*Armillaria mellea* (Vahl.) Quel.
Rust, white pine blister	*Cronartium ribicola* Fisher
Woodgate gall	*Cronartium* sp.

Common and Scientific Names of Insects Mentioned in the Text

Common Name	Scientific Name
Ant, mound-building	*Formica exsectoides* Forel
Bark beetle, mountain pine	*Dendroctonus monticolae* Hopk.
southern pine	*Dendroctonus frontalis* Zimm.
western pine	*Dendroctonus brevicomis* Lec.
Beetle, calosoma	*Calosoma sycophanta* L.
Japanese	*Popillia japonica* Newm.
Borer, eastern hemlock	*Melanophila fulvoguttata* Harr.
Borer, locust	*Cyllene robiniae* Forst.
Budworm, spruce	*Archips fumiferana* Clem.
Grubs, white	*Phyllophaga* sp.
Moth, fir tussock	*Hermerocampa pseudotsuga* McDun.
gypsy	*Porthetria dispar* L.
pandora	*Coloradia pandora* Blake
Sawfly, European spruce	*Diprion polytomum* Hart
larch	*Lygaeonematus crichsonii* Hartig
Sawyer, pine	*Monochamus scutellatus* Say
Scale, golden oak	*Asterolecanium variolosum* Ratz.
Weevil, pales	*Hylobius pales* Boh.
white pine	*Pissodes strobi* Peck

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